DEVELOPMENT OF AN "OPERATIONS" MODEL FOR MONTANA'S WATER RESOURCES

MIDDLE CREEK RESERVOIR OPERATION

Montana University Joint
Water Resources Research Center

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by

Theodore T. Williams
and
G. V. V. Rao

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MONTANA STATE UNIVERSITY
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INTRODUCTION

Throughout Montana and across the nation the insatiable demands for water become greater and greater each year. Even in a water-rich state like Montana, there are many areas where water shortages have become more and more frequent and prolonged in recent years. The needs of an expanding population, coupled with ever-increasing per capita use of water make it imperative that those agencies responsible for managing this vital resource have at their disposal every tool that will help them do the most efficient and effective job possible.

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The Water Resources Division of the Montana Department of Natural Resources and Conservation (successor to the State Water Conservation Board and more recently the Montana Water Resources Board) has been a major factor in the development of water resources in Montana. A total of 181 projects (45 of them major) including storage dams, diversion works, canals and structures, located in 50 of the state's 56 counties, have been constructed in whole or in part by this Agency. At one time or another the Department has been directly or indirectly associated with 773 separate projects, and at present has direct interest in about 100 projects. Each project is a separate enterprise, paid for by local users, and ultimately (after construction costs are repaid) each will revert to local ownership. Most Department projects were constructed as single-purpose irrigation units.

Until the present time, the Department projects have enjoyed a high degree of autonomy, with the Department providing mainly advisory and engineering services. Day-to-day operations have been controlled by local boards of directors. The various projects are regulated according to their water rights through the District Courts of the State, but such regulation does not constitute management to achieve optimal or multiple-purpose benefits. With the present impetus toward water conservation, and with the mandate given the Department by the State Legislature (in 1967) to develop and administer a State Water Plan, it is evident that the Department is going to have to play a more active role in the day-to-day operation of its own projects, and must prepare for the day when it will have to supervise the operation of non-Department projects as well.

In 1970 a proposal was submitted, asking for matching funds (Section 101) to conduct research aimed at the development of a "reservoir operations model." The model would be a series of mathematical relationships programmed for solution on a digital computer. It would incorporate operating rules and guidelines for each of the reservoirs in a given drainage basin, together with

current and historic hydrologic information, and would provide instructions for regulating the major components of the Water Resources Division projects.

The original proposal was not funded; but in 1971 the Montana University Joint Water Resources Research Center made funds available under the Center's allotment program for a one-year first-phase or "pilot" study. After discussions with engineers of the Water Resources Division and the U.S. Soil Conservation Service, and because of the limited time and funding available, it was decided to limit the study to preliminary analyses of one single-purpose reservoir. Hyalite Reservoir on Hyalite Creek (or Middle Creek) in Gallatin County, Montana, was selected for study.

HYALITE RESERVOIR

Hyalite Reservoir was constructed by the State Water Conservation Board (predecessor of the Water Resources Division of the Department of Natural Resources and Conservation) as a U.S. Public Works Administration project. It was completed in 1951. Individual users and groups of users (all farmers except for the City of Bozeman) in the Gallatin Valley entered into contracts with the Board whereby the users reimburse the State for the State's share of the construction costs, and pay the operation and maintenance costs for the project. Each contract specifies a volume of water (in acre feet) to which the user is entitled each year. This water is available to him from the reservoir on call.

Appendix A shows a list of users, and the volumes of water for which they have contracted. A total of 7,795 acre feet per year has been contracted. The reservoir has a useful storage capacity of 8,030 acre feet (U.S. Geological Survey figure).

The users are organized into the Middle Creek Water Users Association,

governed by a Board of Directors elected annually. The present secretary of the Board, Mr. A. C. Manry, directs the operation and maintenance of the project.

GENERAL STRATEGY FOR STUDY

Generally, developing optimum operation rules for a reservoir consists of the following phases:

(1) Collection and compilation of inflow data. If sufficient data are not available, devise a method to generate synthetic data.
(2) Identify the various purposes for which the reservoir releases are being used and develop a common measure of effectiveness.
(3) Devise optimization methods, which will optimize any given objective using the above inflows and subject to any restrictions imposed by the physical conditions of the reservoir like the size, discharge capacity, etc. and policy of the management like fixing priorities between the various users, etc.

STUDIES MADE IN CONNECTION WITH HYALITE RESERVOIR

Reservoir Inflows

In connection with specific studies for Hyalite reservoir, the first phase itself created some problems. There is a U.S.G.S. gaging station about 7 miles downstream from the reservoir on Hyalite Creek (USCS Station 06050000-MSU Data Bank Number 41H03291-Hyalite Creek at Hyalite Ranger Station near Bozeman). Records of flow at this station are available from 1935 to the present. However, the natural flows have been affected by the operation of the reservoir since 1951. The only data available with regard to the operation of the reservoir were the monthly contents of the reservoir as recorded by

the U.S.G.S. (USGS Station 06049500-MSU Data Bank Number 41H93290-Middle Creek Reservoir). With the help of this data, it was possible to reconstruct the natural flows at the gage site on a monthly basis since the construction of the reservoir by adding changes in reservoir contents to the flow volume recorded for that month at the gage. This reconstructed data was tested by a double mass analysis. The natural flows recorded at the Hyalite gage before construction of the reservoir (1935-1951) and the reconstructed natural flows (1951-1967) were compared with flows recorded during the same period in the West Gallatin River at Gallatin Gateway. The correlation between the flows was striking (see Figure 1 and Appendix B).

Another effort made was to synthesize data from the natural flows available from 1935-50. Using the statistics of the flows for these 16 years, the following model from the Harvard Water Program as published in "Design of Water Resources Systems," was adopted for generation of flows.

$$Q_{I+1,J+1} = \overline{Q}_{j+1} + b_i(Q_{i,j} - \overline{Q}_j) + t_i\sigma_{j+1}(1 - \gamma_j^2)^{1/2}$$

where $Q_{i,j}$ = flow generated for year i and month j

j = month

i = year

γ_j = correlation between natural flows for month j and month j+1

σ_j = standard deviation of natural flows for month j

$b_j = \gamma_j(\sigma_{j+1}/\sigma_j)$

As a trial 16 more years of flow were generated. Hydrographs of natural flow and synthesized flow are shown in Figure 2, for comparison. The line labelled "natural flows" was obtained from the average monthly flows which occurred for the 16 years 1935-1950 inclusive. The line labelled "synthesized flows" was obtained from the average monthly flows which were generated for 16 years by the synthesis technique. There seems to be striking agreement between the

FIGURE 1

Comparison of Hyalite Flows with
West Gallatin Flows (1935-1969)

Note: Hyalite flows 1951-1969 have
been adjusted for change in storage
at Middle Creek Reservoir.

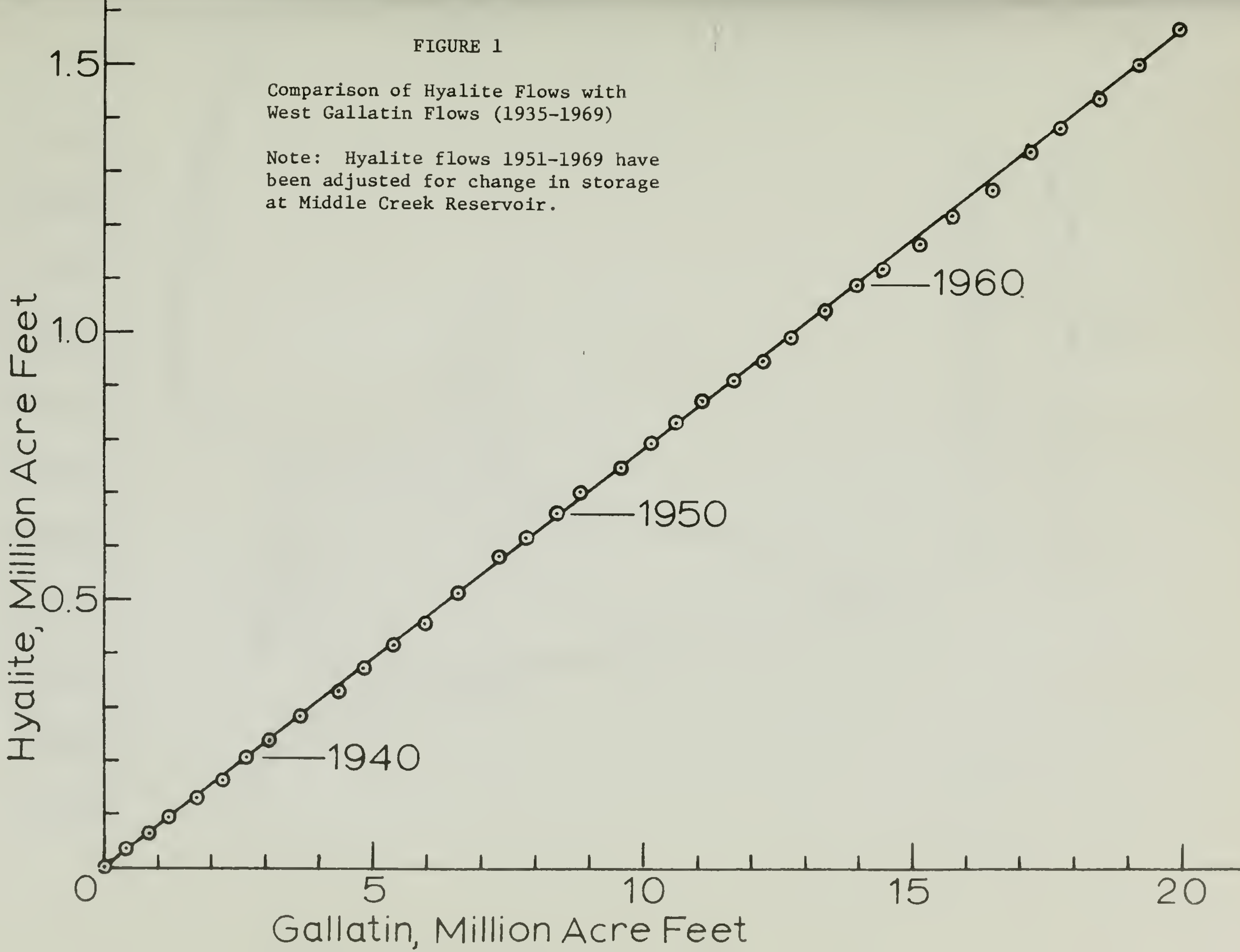
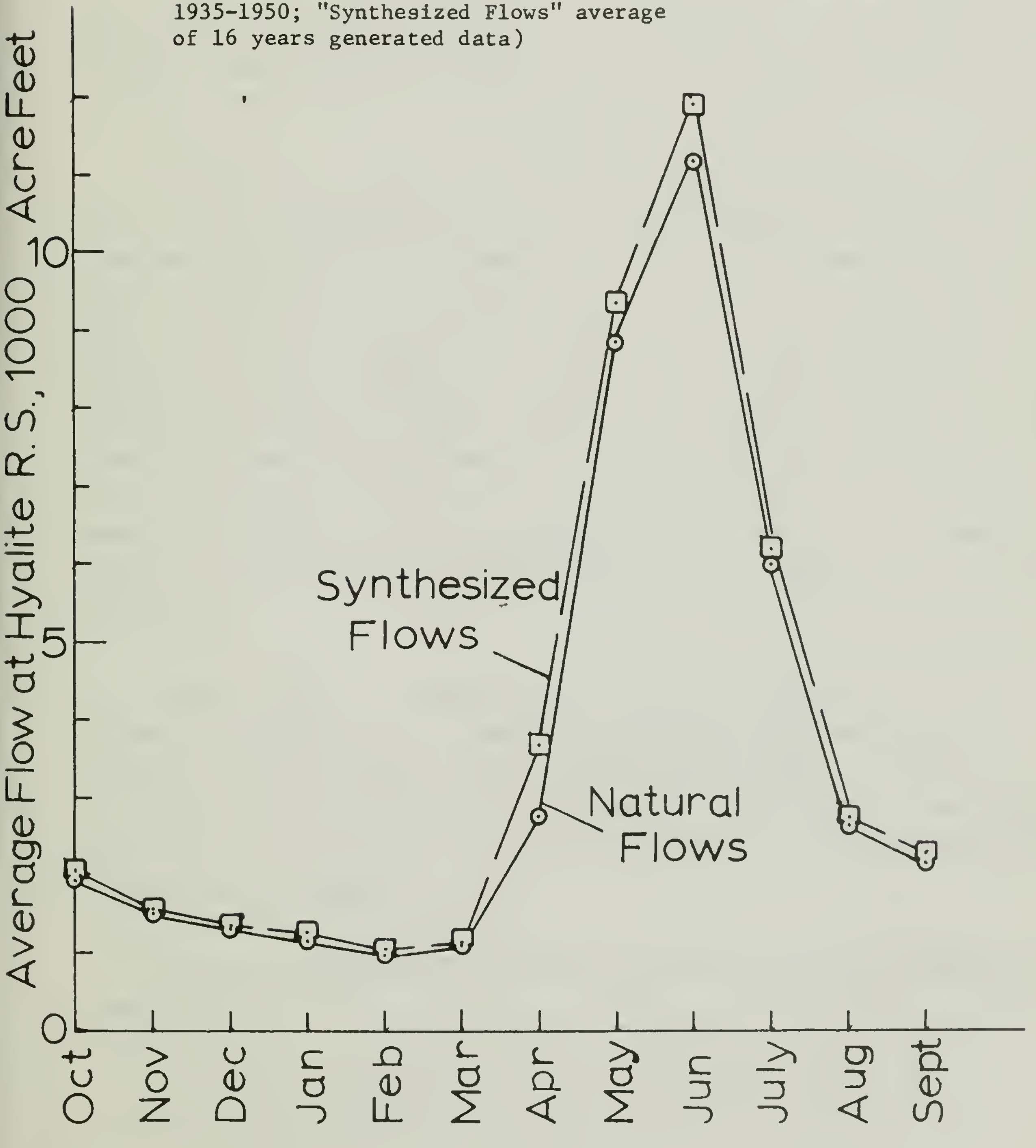


FIGURE 2

Hydrographs of Natural and "Synthesized" Flows at Hyalite Ranger Station

("Natural Flows" average of 16 years 1935-1950; "Synthesized Flows" average of 16 years generated data)



two hydrographs, though the "generated" flows seem to indicate slightly higher peaks.

In further analyses reported herein, the flows as reconstructed from the double mass analysis with the Gallatin River are used. If future detailed analyses requiring several sequences of flows should be attempted, the procedure for synthesis of flows described above could be used.

While the double mass analysis described earlier established a reasonably good method for computing the natural flows at the gage site in spite of the reservoir, estimation of the amount of inflow into the reservoir presented more difficulties. Two branches of Hyalite Creek, viz, the West Fork and the East Fork, feed into the reservoir. While limited observations of flows (in the summer months of 1966-69) are available on West Fork, the flows in East Fork were measured in a Parshall flume only during the summer of 1969. The flows in the West Fork were subjected to double mass analysis with flows at the downstream gage and with flows in the West Gallatin River at Gallatin Gateway (Figure 3). From this analysis it appears that a fair estimate of the flows in the West Fork can be taken as 45% of the adjusted flow at the downstream gage.

Studies made by Phil Farnes (U.S. Soil Conservation Service) and by Michael Watson (MSU) indicate that the total inflow into the reservoir is about 64% of the adjusted flow at the downstream gage. Farnes used snow survey data in working out a water budget for the basin; Watson compared Hyalite flows with flows from Sourdough water shed (a similar basin adjacent to Hyalite on the east).

Using this proportion the inflows into the reservoir were estimated on a monthly basis.

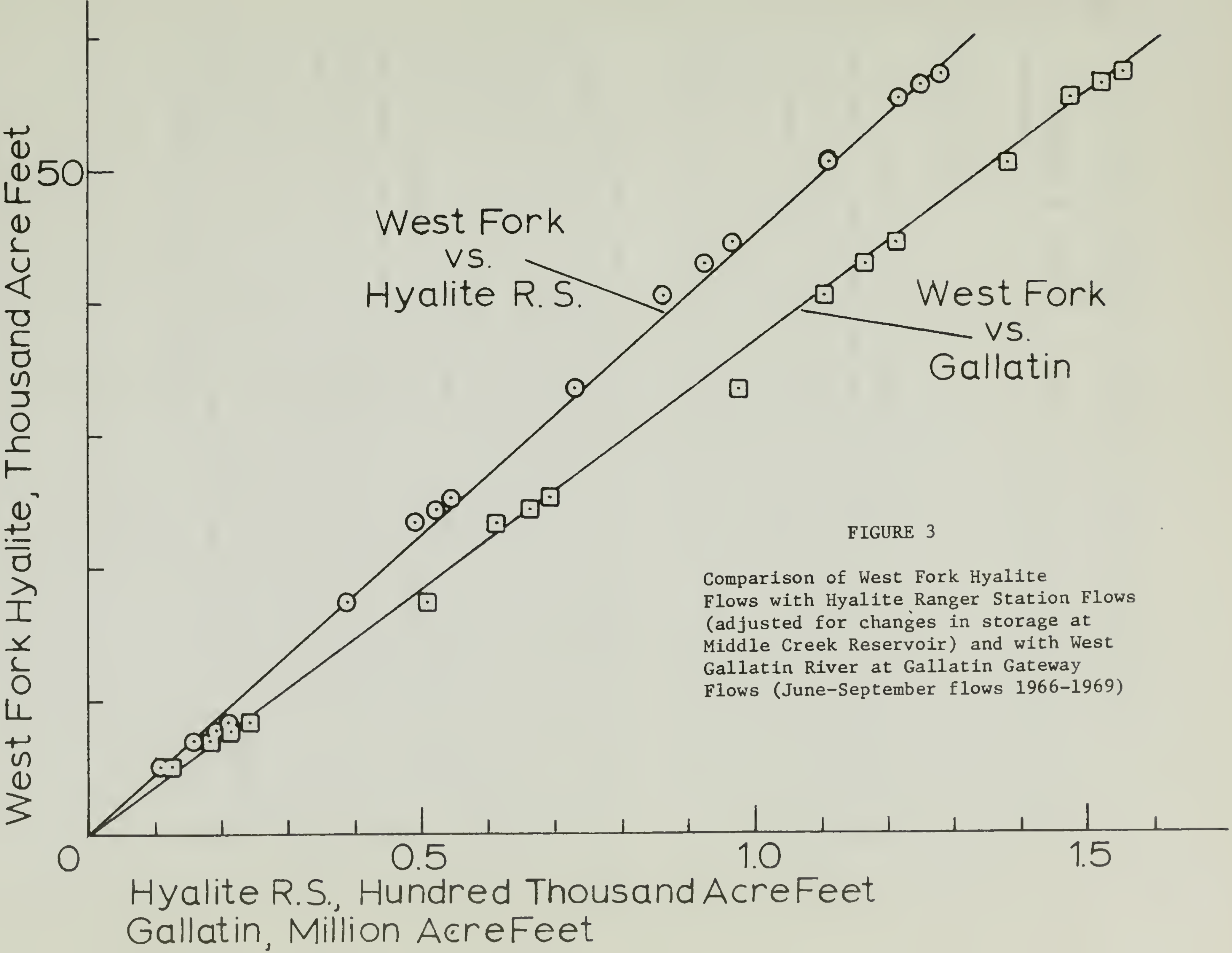


FIGURE 3

Comparison of West Fork Hyalite Flows with Hyalite Ranger Station Flows (adjusted for changes in storage at Middle Creek Reservoir) and with West Gallatin River at Gallatin Gateway Flows (June-September flows 1966-1969)

A computer program was written for this phase of the work.

Appendix B shows the monthly inflows. Appendix C shows Snow Survey measurements.

Reservoir Uses

The reservoir is used by members of the Middle Creek Water Users Association. The primary use is irrigation, but the City of Bozeman has contracts for 2510 acre feet (nearly 1/3 of the reservoir capacity) for municipal water supply. There is some recreation use of the reservoir itself, particularly from residents of the City of Bozeman. Late summer flows in Hyalite Creek downstream from the reservoir are augmented by reservoir releases thereby enhancing fishing and other recreation use along the stream.

With proper reservoir regulation a limited amount of flood control may be possible downstream from the reservoir. The maximum discharge observed at Hyalite Creek at the Hyalite Ranger Station was 956 cfs (in 1898). Since construction of the reservoir in 1951 the discharge has reached 866 cfs once (in 1970) and 600 cfs twice (in 1959 and 1968). (Reference - USGS records.) The 1959, 1968 and 1970 flows apparently caused no flooding problems. Bozeman newspapers published during the high flow periods for each of the three years were searched for reference to flooding. The May 19, 1970 Bozeman Chronicle reported flooding elsewhere in the Gallatin Valley, and alluded to flood potential in the Hyalite dainage, but subsequent issues did not report any Hyalite flooding. The Gallatin County Tribune for December 26, 1968 reported flooding in Hyalite Canyon, but this was a result of ice jams and occurred at a time when flow at the Hyalite Ranger Station was only 20 cfs. (See newspaper accounts, Appendix D).

Reservoir Filling Operations

The objective of an irrigation reservoir operator with respect to reservoir filling is to achieve a full reservoir by the end of the snowmelt runoff period. The most common operations practice is to fill the reservoir with the first water melted in the spring. Any snowmelt in excess of that required for filling is then passed over the spillway. This practice has a two-fold disadvantage. First, the reservoir is often full before the peak snowmelt discharge occurs, and the peak must be passed undiminished over the spillway, perhaps to cause flooding downstream. (Presence of the reservoir can, under some circumstances, produce even higher peak flows downstream than would have occurred without the reservoir). Second, the peak flow may be great enough to endanger the spillway itself.

Snow survey measurements have been made in Montana since 1922. The snow course network has been greatly expanded and procedures have been improved and standardized by the U.S. Soil Conservation Service. Streamflow forecasts (based on multiple regression techniques) are made available by the SCS as of the 1st of March, 1st of April, and 1st of May each year. Using the streamflow forecasts, it should be possible to effect considerable flood mitigation in high runoff years. If it is evident on the 1st of March that the snowpack is well above normal, then the early snowmelt could be released, and high flows during the peak of the melt period could be stored.

Two snow course stations in the Hyalite drainage above Hyalite Reservoir have been operated since before construction of the reservoir. These are Hood Meadow and Devils Slide. Figure 4 shows the average water content in the snow at these two sites on the 1st of April and 1st of May each year, plotted against April-July and May-July adjusted streamflow volume measured at the Hyalite Ranger Station. Figure 4 shows fair agreement for most years between snow pack water content and streamflow volume. Figure 5 shows a plot

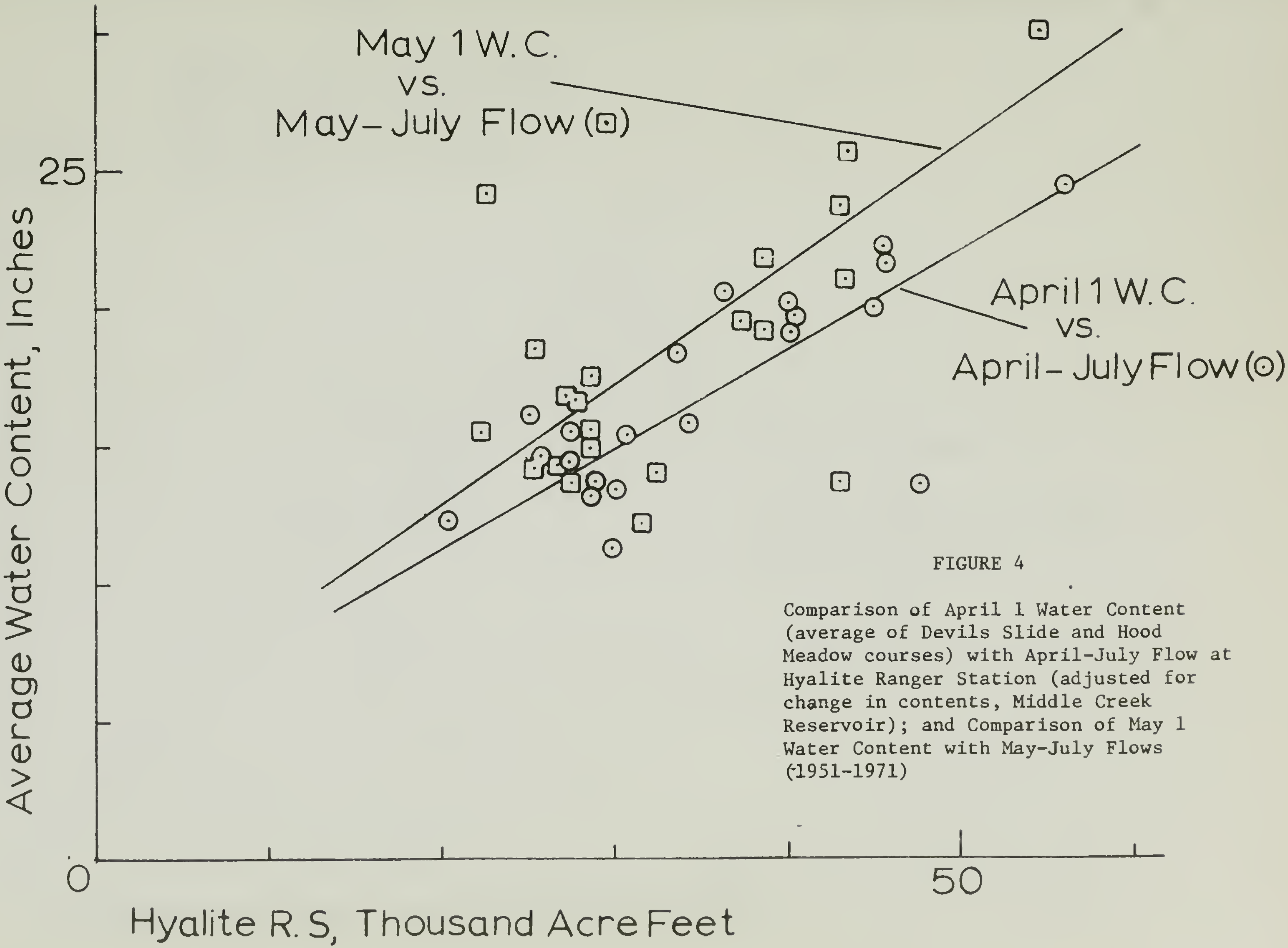
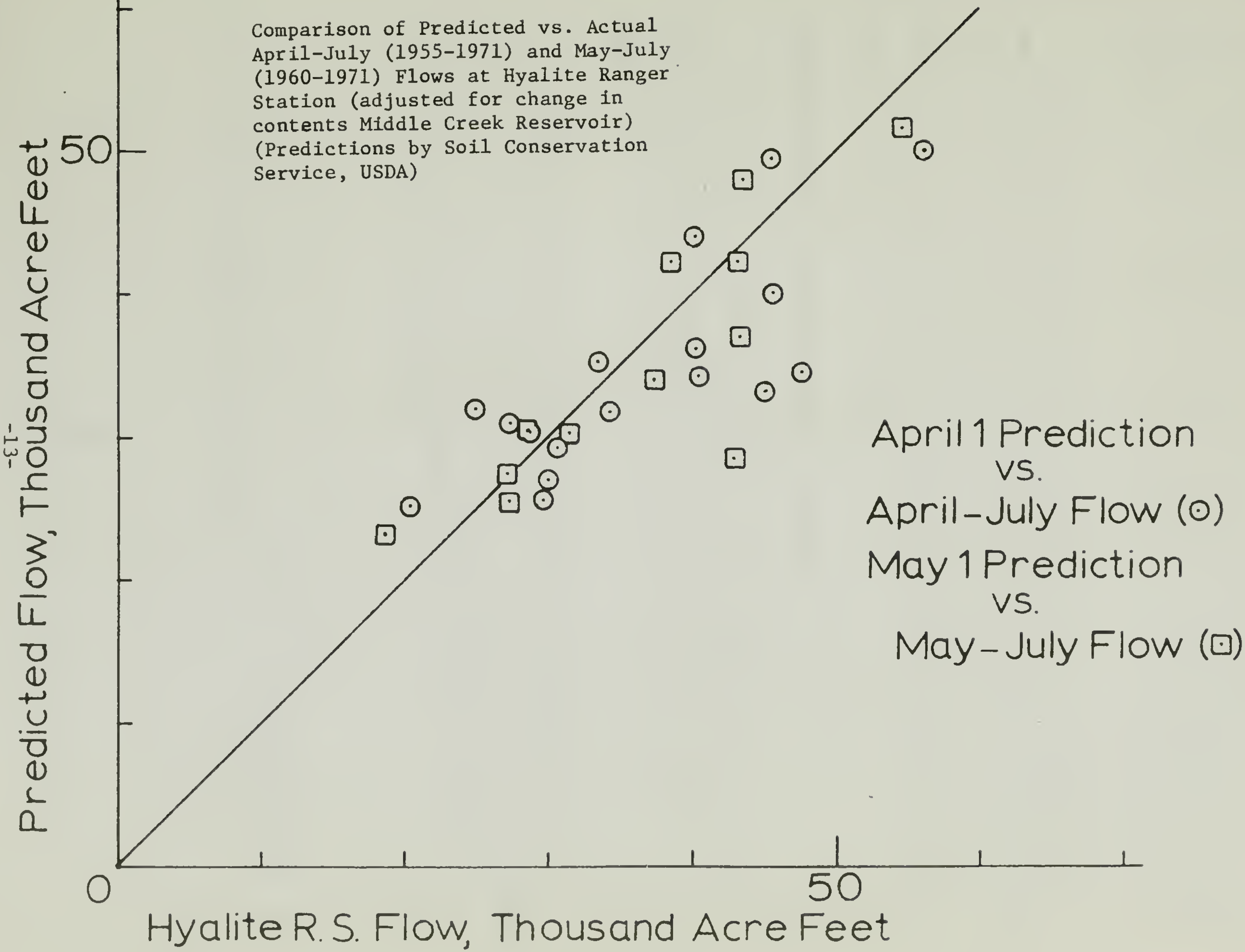


FIGURE 4

Comparison of April 1 Water Content (average of Devils Slide and Hood Meadow courses) with April-July Flow at Hyalite Ranger Station (adjusted for change in contents, Middle Creek Reservoir); and Comparison of May 1 Water Content with May-July Flows (1951-1971)

FIGURE 5

Comparison of Predicted vs. Actual April-July (1955-1971) and May-July (1960-1971) Flows at Hyalite Ranger Station (adjusted for change in contents Middle Creek Reservoir) (Predictions by Soil Conservation Service, USDA)



of April 1st forecasts of April-July streamflow volume vs. April-July actual flows, and May 1st forecasts of May-July streamflow volume vs. May-July actual flows. (All flows have been adjusted to reflect changes in Hyalite Reservoir storage). Figure 5 shows rather good agreement between predicted and actual flows.

Montana Snow Survey Supervisor Phil Farnes reports that other factors besides snow pack information may be used in the streamflow prediction formula; he also indicates that the formula used is revised frequently. The snow course network in the Hyalite drainage has been expanded considerably since 1951 and now includes 5 stations. Farnes declined to release the prediction formula currently in use for Hyalite.

Flood Mitigation by Reservoir Filling Management

The preceding information suggests a method whereby filling of Middle Creek Reservoir could be delayed until late spring, thereby reducing the snowmelt flood peak. The method proposed is based on the following assumptions:

1. Unless the April 1st streamflow forecast is exceedingly low, no reservoir filling is necessary before May 1. (April-July streamflow predictions 1955-1971 were never less than 25,000 acre feet and April-July adjusted streamflows for the same years were never less than 20,000 acre feet -- 2.5 times the capacity of the reservoir).

2. The reservoir is to be full by July 1 each year.

3. May-June predicted inflow to the reservoir is obtained from the May 1 streamflow forecasts by the following:

$$0.78[0.64\ (\text{May-July Streamflow Forecast})]$$

(See earlier discussion indicating reservoir inflow is about 64% of adjusted Hyalite Ranger Station flow; July inflow for years 1951-1971, expressed as a percentage of May-July inflow ranged from 12.4% to 30.4% with the average being 22.0%.)

4. Cumulative reservoir inflow after May 1 can be obtained from:

$$\Sigma[0.64\ (\text{Hyalite Ranger Station Flow} + \text{Reservoir Gain} - \text{Reservoir Loss})]$$

Reservoir inflow yet to come (prior to July 1) is obtained by subtracting the cumulative reservoir inflow (assumption 4) from May-June predicted inflow (assumption 3). It should not be necessary to store any water in the reservoir until the "inflow yet to come" calculation drops to 8000 acre feet. At that point all inflow should be stored. The 36% of "Hyalite Ranger Station" flows originating below the reservoir should be adequate in most cases to meet downstream user demands during the storage period. In actuality of course, some reservoir release will be necessary to meet minimum flow requirements for fish, so the storage period will need to begin somewhat earlier (when the "inflow yet to come" drops to say 10,000 acre feet).

A further safety factor could be attained by allowing for possible inaccuracies in the streamflow forecasts. (See Figure 5).

OPTIMIZATION STUDIES

Actual optimization studies could not be conducted for Hyalite reservoir due to non-availability of actual data at that time. However, operation of a single reservoir like this should not present any real difficulties. Just to demonstrate the possible approaches to solving this problem two pilot studies

one using linear programming techniques and the other using dynamic programming, were made with hypothetical data. Following are brief descriptions of the two studies.

Linear Programming

Let us consider the operation of a single reservoir over a period of 4 seasons. This problem is solved using a canned package called MFORLP, available on Xerox Data Systems - Sigma 7 computer.

1. Mathematical Formulation

a. During Season 1

Let S_1 be the storage available at the beginning of season 1.
Let I_1 be the inflow during season 1.
Let R_1 be the release during season 1.
Let S_2 be the storage at the end of season 1 (and hence at the beginnin of season 2).

Then continuity demands that

$$S_1 + I_1 = R_1 + S_2$$

b. Similarly for Season 2

$$S_2 + I_2 = R_2 + S_3 \qquad \text{etc.}$$

In the problem considered here, S_1 is assumed to be 20 units (say thousands of acre feet). The inflow pattern during a four season cycle is assumed as follows:

Season	1	2	3	4
Inflow (1000 AF)	40	20	10	20

The objective of the operation policy is to maximize profits. The worth of water in various seasons is as given below:

Season	1	2	3	4
Value/Unit	2	10	9	3

The reservoir is assumed to have a maximum capacity of 100,000 AF. It is desired to have a storage of 20,000 AF at the end of season four.

2. Formulation in L.P.

From the above data, the L.P. problem can be formulated as follows:

a. Objective function

$$\text{Max. } Z = 2R_1 + 10R_2 + 9R_3 + 3R_4$$

Subject to the constraints:

1. $R_1 + S_2 = I_1 + S_1 = 20 + 40 = 60$
2. $- S_2 + R_2 + S_3 = 20$
3. $- S_3 + R_3 + S_4 = 10$
4. $- S_4 + R_4 + 20 = 20$
5. $S_2 \leq 100$
6. $S_3 \leq 100$
7. $S_4 \leq 100$

S_i , R_i (i = 1, 2, 3, 4, 5; i = 1, 2, 3, 4) $\geq$ 0.

Computer coding and results may be seen in Appendix E. Discussion of the results of the computer program follow.

b. Interpretation of the Result

The primal solution is

Z_1^* (optimum) = Maximum Revenue = 890 units

$R_1^* = 0$

$R_2^* = 80$

$R_3^* = 10$

$R_4^* = 0$

$S_2^* = 60$

$S_3^* = 0$

$S_4^* = 0$

(Slacks are not included)

It may be noted that maximum possible discharge is recommended in the secor and third seasons when the revenue is maximum. The recommended discharge in fi? season (R_1) is zero, thus conserving water for discharge during the second season, when it brings more revenue.

The Dual

The Dual solution is

Z_2^* (optimum) = minimum cost = 890 units

$Y_1^* = 10$

$Y_2^* = 10$

$Y_3^* = 9$

$Y_4^* = 3$

$Y_5^* = 0$

$Y_6^* = 0$

$Y_7^* = 0$

(slacks are not included)

The inflows during first, second, third and fourth seasons, have imputed values of 10, 10, 9 and 3 units, respectively. This is obvious as increase of inflows during these seasons will help greater releases R_2, R_3 and R_4, bringing revenue of respectively 10, 9 and 3 units respectively. However in real life situations, increasing the inflows is not possible, as they are a result of natural phenomena. Even the assumption of prior knowledge of these inflows is not realistic, as it is usually not possible to know definitely, future inflow pattern.

Dynamic Programming

Let us assume that we have a reservoir which is being used for (1) recreation and (2) flood control. Let us further assume that we can establish the loss in either use associated with any policy, as shown in Figures 6(b) and 6(c). Also, let us assume that we know the inflow for five consecutive seasons: $x(1) = 4$, $x(2) = 1$, $x(3) = 3$, $x(4) = 0$, $x(5) = 4$. Let us consider three states of storage: full (2); half-full (1); and empty (0).

Solution:

Stages = seasons (I) $1 \rightarrow 5$

States = Storage (S) $0 \rightarrow 2$

Decision Variables = Discharge (D) 0 → 2

Procedure:

1) At any stage the starting storage can be 0 → 2, and by any policy we can reach any of the states 0 → 2. (Of course, the limitations are: (i) the beginning storage (K) cannot be more than ending storage (J) - inflow in the season (X(I)); and (ii) the ending storage (J) cannot be more than beginning storage (K) + inflow in the season (X(I)) and both cannot be more than the full storage (2) or less than no storage (0)).

2) The loss (L) associated with our policy in any season (I)

L = (Loss due to Recreation LR(J) + Loss due to flood (LF(K + x(I) - J)) in the season + minimum loss due to our policy up to reaching the stage (LMEM(I - 1, K)).

3) As we can start at any state (K) to reach the present state (J), we would like to choose only that state (K*) which minimizes the overall loss, and store this value of K* for later reference.

4) Proceed to calculate the minimum Loss (LMEM) and trace back state (SMEM) associated with each state (J) at each stage (I), until the last stage (Season 5 in this case), is reached.

5) Then select the state which has the overall minimum loss (MINL).

6) Starting from this point trace back to determine the policy. Please see detailed working in Figure 6.

Computer coding and output may be seen in Appendix F.

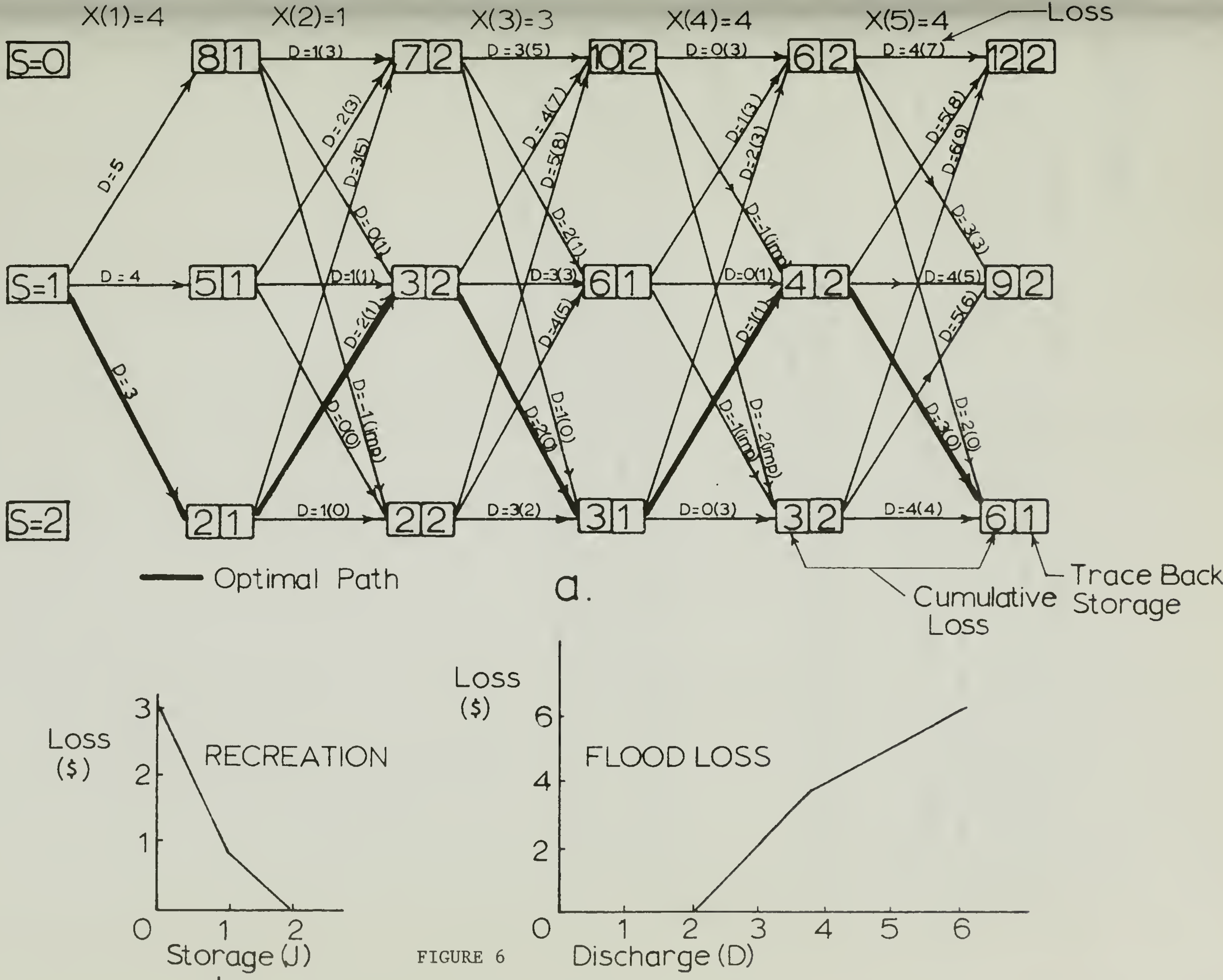


FIGURE 6

Dynamic Programming Example

Other Studies

In connection with another study, an approach to solve reservoir operation problem via simulation in GASP language was attempted. Of course, this simulation approach does not necessarily lead to an optimal solution, but its potentiality for use in reservoir operation situations was demonstrated. This is particularly worth considering in case it is intended to use stochatic inflows.

Several useful references using these techniques have been mentioned in the bibliography of reference 2.

CONCLUSIONS

The study began as a pilot project for a larger investigation involving integrated operation of systems of reservoirs in Montana. The Mussellshell Basin has been chosen for such a study and at present a much more extensive study is underway. The studies described herein formed the groundwork for this larger study, (B-038 MONT).

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APPENDIX A

Members of Middle Creek Water Users Association with Volumes of Hyalite Reservoir Water Contracted

MIDDLE CREEK PROJECT

Term = 30 years

First Payment	Contract No.	Purchaser (as of 1-25-72)	Acre Feet Contract	Acre Feet Yearly Total
1951	1	Aakjer, Ralph & Nick	25	
	2-A-1	Miller, John L.	50	
	3	City of Bozeman	500	
	4	City of Bozeman	550	
	5	Benepe, Frank L., Jr.	25	
	6	Benepe, Lucien L.	50	
	7-A	Boylan, Richard J.	50	
	8	Boylan, Boyd W.	25	
	9-A	Bos, John	50	
	10	Doney, Frank R.	125	
	11-A	Dusenberry, George D.	100	
	12	Dusenberry, Bert L., Jr.	75	
	13-A-1	Lichtenberg, Delbrook & Landoe, H. B.	50	
	14-A	Montana State University	100	
	15-A	Parker, Ora S.	75	
	16	Hansen, Peter M.	50	
	17	Heiskell, Hugh	75	
	18	Johnson, Carl G.	25	
	19-A-2	Schmittroth, Louis	100	
	19-B	Kirk, Marguerite	50	
	21	Kessler, E. E.	100	
	22	Kurk, Lester J.	25	
	23	Kurk, A. J.	20	
	24-A	Bradley, Clyde J.	50	
	25-A	Kraft, Meretta	50	
	25-B	Kraft, Glen	50	
	26	Kraft, Earl	100	
	27-A-1-A	American Fork Ranch	50	
	27-A-2-A	American Fork Ranch, Robert T. Stevens, Pres.	50	
	27-A-3	Lindvig, Einar, Regina & Harold	50	
	28-A	Caprio, Joseph M. & Marilyn	100	
	29	Nash, Jack	50	
	30	Pasha, John R.	50	
	31	Pasha, C. L.	50	
	32	Pasha, C. L.	50	
	33	Pasha, W. D.	50	
	34	Pasha, W. D.	50	

MIDDLE CREEK PROJECT

(Page 2)

First Payment	Contract No.	Purchaser (as of 1-25-72)	Acre Feet Contract	Acre Feet Yearly Total
	35-A	Michel, Albert J. & Ramona M.	25	
	36-A	Kraft, Merretta	100	
	37	Smith, Stanley K.	50	
	38-A-1	Bradley, Elizabeth O.	25	
	39-A-1	Derby, James E. & Emma	20	
	40-A	Miller, Harold E.	150	
	41-A	Montana State University	50	
	42-A-1-B	Westlake, George	50	
	43-A-1-A-1	Lichtenberg, Delbert & Landoe, H. E.	25	
	43-A-1-B-2	Cawlfield, Dave R.	12.5	
	43-A-2	Kraft, Earl C.	50	
	44	Ward, Tom	100	3,752.5
1952	46	Montana State University	300	
	47-A-1	Jordan, Robert & Mardella	25	
	47-B	Wend, David A. A. and/or Alice B.	25	
	48	Clark, E. L.	50	
	49-A	Miller, Harold	35	435
1953	50-A	Miller, Harold	40	
	51-A	Gallatin County	25	
	52-A-1	S.A.C., Inc., Roger L. Craft, President	25	
	52-B	Kraft, Merretta	25	
	53-A	Lichtenberg, Delbert & Landoe, H. B.	25	
	54-A	Jordan, Robert & Mardella	50	
	55	Bradley, Clyde J.	50	
	56-A	Raffety, Lloyd & Mildred	15	
	57-A-1	Fellerhoff, John A. & Ella H.	25	
	57-A-2	Stenger, Edward & Helen	25	
	58-A	White, Edna Tracy	50	
	59-A	Manry, Albert & Lillian	15	
	60-A	Parker, Ora S.	50	
	61-A-1	Lichtenberg, Delbert & Landoe, H. B.	50	

MIDDLE CREEK PROJECT

(Page 3)

First Payment	Contract No.	Purchaser (as of 1-25-72)	Acre Feet Contract	Yearly Total
	62-A	Miller, Mae E.	50	
	63-A	Boylan, Paul F.	50	
	66-A-1	Boyd, J. C.	75	645
1954	67-A-1	Benepe, Lucien L.	50	
	68	Johnson, Carl G.	25	
	69-A	Wolney, David A.	50	
	70-A-1	Shelton, Robert R. & Deborah D. & Shelton Interests, Inc.	50	
	72	Westlake, Myron M.	50	
	73	Bradley, James C.	50	
	74-A	City of Bozeman	10	
	75-A-1	Westland, George F. & Nancy J.	50	
	76-A	Dusenberry, George E.	50	385
1955	77	Dyk, Peter S.	200	
	78	Cawlfield, Dave R.	40	
	79-A	Sabo, Dr. F. I. & Dorothy F.	100	
	81-A	Cline, C. E. & Louise C.	50	
	82-A	Raffety, Lloyd & Mildred	50	
	84	Lang, Vernon J.	100	
	85-A	Walker, Edwin & Hilda H.	30	
	86	Hoppel, Fred G.	20	590
1956	20-A-1	Miller, E. Mae	25	
	20-B-1	Dogterom, C. A. and/or McChesney, A. L.	50	
	20-C	Wolney, David A.	50	
	38	City of Bozeman	1450	
	89-A-1	Shelton, Robert R. & Deborah D.	50	1625
1958	45-A-1	Lane, Thomas E. & Robert D.	100	
	64-A	Wheeler, James E. & Ethel C.	15	
	71-A	Ward, Tom	50	
	83-A-1	Vincent, Tom E. & Marjorie S.	50	
	90-A	McCrosson, John W., Jr.	12.5	
	91-A	Walker, Edwin & Hilda H.	20	247.5
1959	92-A-2	Lee, Clara B.	40	

MIDDLE CREEK PROJECT

(Page 4)

First Payment	Contract No.	Purchaser (as of 1-25-72)	Acre Feet Contract	Acre Feet Yearly Total
	92-B	Amunrud, Leroy & Dorris	20	60
1960	93	Miller, Robert W. & Elizabeth P.	20	
	95	Clark, Clifford A. & Mildred	20	40
1961	94	Raffety, Lloyd & Mildred	10	10
1966	96-A	Bennett, Marshall B. and/or Ciluzann	20	20
		Total Contracts		7,810

APPENDIX B

Streamflows at Hyalite Creek
with Reservoir Releases

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1950	Oct	2060	0	0	2060					
	Nov	1810			1810					
	Dec	1740			1740					
1951	Jan	1500			1500					
	Feb	992			992					
	Mar	653			653					
	Apr	1360	1790	+1790	3150	2015	225	25710		
	May	6880	5360	+3570	10450	6690	3120		22560	
	Jun	7330	4880	- 480	6850	4390	4870			
	Jul	6120	4020	- 869	5260	3360	4220			23.4 %
	Aug	4070	2560	-1460	2610					
	Sep	1980	2660	+ 100	2080					
	Oct	2190	2520	- 140	2050					
	Nov	1610	2270	- 250	1360					
	Dec	1370	2120	- 150	1220					
1952	Jan	1090	2600	+ 480	1570					
	Feb	1060	2600	0	1060					
	Mar	1150	2570	- 30	1120					
	Apr	3240	3290	+ 720	3960	2535	1815	36410		
	May	11280	4470	+1180	12460	7960	6780		32450	
	Jun	13340	5270	+ 800	14140	9050	8250			
	Jul	6360	4760	- 510	5850	3740	4250			18.0 %
	Aug	4000	3730	-1030	2970					
	Sep	2770	2940	- 790	1980					
	Oct	1750	2820	- 120	1630					
	Nov	881	3190	+ 370	1251					
	Dec	700	3750	+ 560	1260					
1953	Jan	815	4100	+ 350	1165					
	Feb	845	4710	+ 610	1455					
	Mar	829	4980	+ 270	1099					
	Apr	1480	5480	+ 500	1980	1270	770	28700		
	May	5450	5680	+ 200	5650	3620	3420		26720	
	Jun	13740	5440	- 240	13500	8650	8890			
	Jul	8540	4450	- 970	7570	4850	5820			28.3 %
	Aug	5360	1480	-2990	2370					
	Sep	2330	1150	- 330	2000					
	Oct	1760	1240	+ 90	1850					

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1953	Nov	1080	1640	+ 400	1480					
	Dec	863	2320	+ 680	1543					
1954	Jan	579	2640	+ 320	899					
	Feb	635	3300	+ 660	1295					
	Mar	625	4250	+ 950	1575					
	Apr	1550	4760	+ 510	2060	1320	810	27480		
	May	6200	6440	+1680	7880	5040	3360		25420	
	Jun	10540	6520	+ 80	10620	6800	6720			
	Jul	8240	5200	-1320	6920	4430	5750			27.2 %
	Aug	5670	2470	-2830	2840					
	Sep	1680	2420	- 50	1630					
	Oct	1350	2410	- 10	1340					
	Nov	959	2600	+ 190	1149					
	Dec	801	3430	+ 830	1631					
1955	Jan	498	4230	+ 800	1298					
	Feb	541	4710	+ 480	1021					
	Mar	559	5190	+ 480	1039					
	Apr	781	5640	+ 450	1231	788	338	28991		
	May	7890	5940	+ 300	8190	5240	4940		27760	
	Jun	12820	6540	+ 600	13420	8600	8000			
	Jul	7160	5530	-1010	6150	3940	4950			22.2 %
	Aug	6060	2100	-3430	2630					
	Sep	1810	1730	- 370	1440					
	Oct	1760	1690	- 40	1720					
	Nov	998	1820	+ 130	1128					
	Dec	633	2560	+ 740	1373					
1956	Jan	680	3030	+ 470	1150					
	Feb	553	3350	+ 320	873					
	Mar	839	3670	+ 320	1159					
	Apr	1920	4510	+ 830	2760	1770	930	25040		
	May	5820	5760	+1250	7070	4520	3270		22280	
	Jun	11500	6180	+ 420	11920	7640	7220			
	Jul	6050	3420	-2760	3290	2110	4870			14.75%
	Aug	4050	1320	-2100	1950					
	Sep	2030	1150	- 170	1860					
	Oct	1710	1170	+ 20	1730					
	Nov	692	1870	+ 700	1392					

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1956	Dec	750	2450	+ 580	1330					
1957	Jan	589	2840	+ 390	979					
	Feb	640	3110	+ 270	910					
	Mar	835	3430	+ 320	1155					
	Apr	1130	3700	+ 270	1400	895	625	30050		
	May	5180	5840	+2140	7320	4690	2550		28650	
	Jun	13850	7660	+1820	15670	10000	8180			
	Jul	6620	6700	- 960	5660	3620	4580			19.8 %
	Aug	5270	3620	-3080	2190					
	Sep	2090	3480	- 140	1950					
	Oct	1770	3420	- 60	1710					
	Nov	1330	3440	+ 20	1350					
	Dec	1290	3470	+ 30	1320					
1958	Jan	1270	3490	+ 20	1290					
	Feb	893	3680	+ 190	1083					
	Mar	831	3960	+ 280	1121					
	Apr	1450	4520	+ 560	2010	1285	725	27440		
	May	8760	7660	+3140	11900	7620	4480		25430	
	Jun	9040	7660	0	9040	5790	5790			
	Jul	5450	6700	- 960	4490	2870	3830			17.65%
	Aug	4850	4470	-2230	2620					
	Sep	2470	3790	- 680	1790					
	Oct	1970	3370	- 420	1550					
	Nov	1170	3670	+ 300	1470					
	Dec	1060	3930	+ 260	1320					
1959	Jan	1040	4160	+ 230	1270					
	Feb	895	4200	+ 40	935					
	Mar	1040	4310	+ 110	1150					
	Apr	1780	4890	+ 580	2360	1510	930	40470		
	May	7300	6880	+1990	9290	5940	3950		38110	
	Jun	19050	7660	+ 780	19830	12700	11920			
	Jul	9770	6880	- 780	8990	5750	6530			23.6 %
	Aug	6220	3600	-3280	2940					
	Sep	2740	3420	- 180	2560					
	Oct	2520	3540	+ 120	2640					
	Nov	2110	3540	0	2110					
	Dec	1340	3770	+ 230	1570					

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	REs. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1960	Jan	1140	3960	+ 190	1330					
	Feb	1050	4220	+ 260	1310					
	Mar	1270	4430	+ 210	1480					
	Apr	2560	5350	+ 920	3490	2234	1314	30720		
	May	5940	6880	+1530	7470	4781	3251		27230	
	Jun	12840	7860	+ 980	13820	8845	7865			
	Jul	8800	5000	-2860	5940	8302	6662			21.8 %
	Aug	5510	2400	-2600	2910					
	Sep	2240	1920	- 480	1760					
	Oct	1480	1970	+ 50	1530					
	Nov	1020	2350	+ 380	1400					
	Dec	473	2870	+ 520	993					
1961	Jan	387	3190	+ 320	707					
	Feb	714	3490	+ 300	1014					
	Mar	815	3830	+ 340	1155					
	Apr	1120	4520	+ 690	1810	1158	468	20550		
	May	4010	7470	+2950	6960	4454	1504		18740	
	Jun	9720	7200	- 270	9450	6048	6318			
	Jul	6040	3490	-3710	2330	1491	5201			12.4 %
	Aug	3600	1640	-1850	1750					
	Sep	2150	1370	- 270	1880					
	Oct	262	1530	+ 160	2780					
	Nov	1430	1730	+ 200	1630					
	Dec	1030	1980	+ 250	1280					
1962	Jan	803	2300	+ 320	1123					
	Feb	889	2510	+ 210	1099					
	Mar	1060	2720	+ 210	1270					
	Apr	3160	4400	+1680	4840	3098	1418	33600		
	May	6520	7270	+2870	9390	6010	3140		28760	
	Jun	11510	7920	+ 650	12160	7782	7132			
	Jul	7210	7920	0	7210	4614	4614			25.1 %
	Aug	6310	5300	-2620	3690					
	Sep	3250	4540	- 760	2490					
	Oct	2680	4060	- 480	2200					
	Nov	983	4130	+ 70	1053					
	Dec	1850	4140	+ 10	1860					
1963	Jan	1000	4320	+ 180	1180					

		Discharge at Hyalite Ranger Station	Middle Creek REservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1963	Feb	897	4730	+ 410	1307					
	Mar	1080	5140	+ 410	1490					
	Apr	2600	5280	+ 140	2740	1754	1613	34310		
	May	9010	8030	+2750	11760	7526	4776		31570	
	Jun	13980	7970	- 60	13920	8909	8969			
	Jul	7950	5910	-2060	5890	3770	5830			18.6 %
	Aug	5870	3000	-2910	2960					
	Sep	2770	2360	- 640	2130					
	Oct	1690	2470	+ 110	1800					
	Nov	1200	2670	+ 200	1400					
	Dec	885	2770	+ 100	985					
1964	Jan	590	2890	+ 120	710					
	Feb	668	3010	+ 120	788					
	Mar	649	3290	+ 280	929					
	Apr	1010	5050	+1760	2770	1773	13	40130		
	May	9470	7170	+2120	11590	7418	5298		37360	
	Jun	14920	7970	+ 800	15720	10061	9261			
	Jul	11130	6890	-1080	10050	6432	7512			26.95%
	Aug	7290	3360	-3530	3760					
	Sep	2300	2890	- 470	1830					
	Oct	2170	3000	+ 110	2280					
	Nov	1400	3110	+ 110	1510					
	Dec	1790	3460	+ 350	2140					
1965	Jan	1290	3760	+ 300	1590					
	Feb	1140	3930	+ 170	1310					
	Mar	1520	3990	+ 60	1580					
	Apr	2240	4130	+ 140	2380	1523	1383	45740		
	May	9780	5130	+1000	10780	6899	5899		43360	
	Jun	16770	7790	+2660	19430	12435	9775			
	Jul	13470	7470	- 320	13150	8416	8736			30.4 %
	Aug	7100	4610	-2860	4240					
	Sep	6940	1160	-3450	3490					
	Oct	3470	391	- 769	2701					
	Nov	1680	819	+ 428	2108					
	Dec	1320	1170	+ 351	1671					
1966	Jan	1240	1360	+ 190	1430					
	Feb	873	1780	+ 420	1293					

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July Flow
1966	Mar	809	2350	+ 570	1379					
	Apr	1500	3290	+ 940	2440	1562	622	29860		
	May	6480	8240	+4950	11430	7315	2365		27420	
	Jun	10870	7970	- 270	10600	6784	7054			
	Jul	8520	4840	-3130	5390	3450	6580			19.65%
	Aug	5810	2150	-2690	3120					
	Sep	2530	1560	- 590	1940					
	Oct	2460	1150	- 410	2050					
	Nov	1160	1360	+ 210	1370					
	Dec	863	2060	+ 700	1563					
1967	Jan	686	2600	+ 540	1226					
	Feb	641	3000	+ 400	1041					
	Mar	795	3480	+ 480	1275					
	Apr	1070	3920	+ 440	1510	966	526	40110		
	May	7750	6620	+2700	10450	6688	3988		38600	
	Jun	16730	7990	+1370	18100	11584	10214			
	Jul	10460	7580	- 410	10050	6432	6842			26.0 %
	Aug	6950	3670	-3910	3040					
	Sep	3090	2740	- 930	2160					
	Oct	2220	3060	+ 320	2540					
	Nov	2090	3100	+ 40	2130					
	Dec	1820	3120	+ 20	1840					
1968	Jan	1430	3340	+ 220	1650					
	Feb	1370	3330	- 10	1360					
	Mar	1580	3360	+ 30	1610					
	Apr	1820	3470	+ 110	1930	1235	1125	45030		
	May	7980	6880	+3410	11390	7290	3880		43100	
	Jun	17590	7970	+1090	18680	11955	10865			
	Jul	13380	7620	- 350	13030	8339	8689			30.2 %
	Aug	7850	6000	-1620	6230					
	Sep	5150	5400	- 600	4550					
	Oct	4930	4450	- 950	3980					
	Nov	3690	2900	-1550	2140					
	Dec	1530	2970	+ 70	1600					
1969	Jan	1260	3480	+ 510	1770					
	Feb	901	3800	+ 320	1221					
	Mar	1360	4030	+ 230	1590					

		Discharge at Hyalite Ranger Station	Middle Creek Reservoir, month-end contents	Net change in storage	Adjusted Discharge at Ranger Station	Res. Inflow (Adj. Flow x 64%)	Reservoir Releases	Apr-July Adjusted Flows	May-July Adjusted Flows	July Adj. Flow as % of May-July flow
	Apr	3560	5180	+1150	4710	3014	1864	47720		
	May	15270	7820	+2640	17910	11462	8822		43010	
	Jun	14500	8080	+ 260	14760	9446	9186			
	Jul	11090	7330	- 750	10340	6618	7368			24.0 %
	Aug	6480	4250	-3080	3400					
	Sep	3460	3470	- 780	2680					
	Oct	2750	3150	- 320	2430					
	Nov	1650	3140	- 10	1640					
	Dec	1460	3370	+ 230	1690					
1970	Jan	1010	3770	+ 400	1410					
	Feb	1150	4100	+ 330	1480					
	Mar	1190	4400	+ 300	1490					
	Apr	1350	4430	+ 30	1380	883	853	56100		
	May	16760	5400	+ 970	17730	11347	10377		54720	
	Jun	22780	7860	+2460	25240	16154	13694			
	Jul	12260	7350	- 510	11750	7520	8030			21.45%
	Aug	6850	4950	-2400	4450					
	Sep	4810	3700	-1250	3560					
	Oct	3630	3150	- 550	3080					
	Nov	2450	2970	- 180	2270					
	Dec	1120	3410	+ 440	1560					
1971	Jan	825	3990	+ 580	1405					
	Feb	1060	4510	+ 520	1580					
	Mar	1250	4820	+ 310	1560					
	Apr	3110	3840	- 980	2130	1363	2343	45640		
	May	11810	5010	+1170	12980	8307	7137		43510	
	Jun	15880	7720	+2710	18590	11898	9188			
	Jul	12720	6940	- 780	11940	7642	8422			27.4 %
	Aug	8190	3370	-3570	4620					
	Sep	4140	2570	- 800	3340					

APPENDIX C

Snow Survey Records

	Snow Survey Date	Arch Falls (7350 ft)	Devils Slide (8100 ft)	Hood Meadow (6600 ft)	Hood Meadow (new) (6600 ft)	Lick Creek (6860 ft)	Shower Falls (8100 ft)	May-June Streamflow Forecast (1000 AF)	April-July Streamflow Forecast	May-July Streamflow Forecast
1945	Mar 1		10.9	4.2						
	Apr 1		15.1	6.2						
1946	Mar 1		18.7	7.7						
	Apr 1		24.2	8.4						
	May 1		22.3	1.3						
1947	Mar 1		16.0	6.2						
	Apr 1		22.6	10.8				10.4		
	May 1		28.2	7.3				12.2		
1948	Mar 1		23.2	11.3						
	Apr 1		27.4	13.3				13.7		
	May 1		30.5	9.9				13.0		
1949	Mar 1		18.1	8.7						
	Apr 1		20.8	10.9				19.0		
	May 1		20.3	1.7				18.0		
1950	Mar 1		12.9	4.3						
	Apr 1		20.2	7.3				19.0		
	May 1		24.5	8.5				19.8		
1951	Mar 1		14.8	6.6						
	Apr 1		19.9	9.4				20.4		
	May 1		18.7	5.5				20.4		
1952	Mar 1		20.5	10.3						
	Apr 1		27.5	13.7						
	May 1		25.6	2.5						
1953	Mar 1		15.6	6.4						
	Apr 1		18.8	7.6						
	May 1		23.3	5.2						
1954	Feb 1		12.3	4.8						
	Mar 1		13.7	5.6						
	Apr 1		20.0	8.8						
	May 1		20.1	2.8						
1955	Feb 1		8.9	2.6						
	Mar 1		12.5	6.3						
	Apr 1		18.6	8.8					30.3	

	Snow Survey Date	Arch Falls (7350 ft)	Devils Slide (8100 ft)	Wood Meadow (6600 ft)	Wood Meadow (new) (6600 ft)	Lick Creek (6860 ft)	Shower Falls (8100 ft)	May-June Streamflow Forecast (1000 AF)	April-July Streamflow Forecast	May-July Streamflow Forecast
	May 1		22.8	10.4					26.0	
1956	Feb 1		16.2	6.2						
	Mar 1		18.5	7.3						
	Apr 1		23.3	9.0					32.0	
	May 1		26.2	4.8					32.0	
1957	Mar 1		14.2	6.2						
	Apr 1		19.1	7.8					27.0	
	May 1		24.6	6.9					27.0	
1958	Feb 1		12.6	7.3						
	Mar 1		17.2	8.6						
	Apr 1		21.4	9.6					31.0	
	May 1		26.6	10.4					31.3	
1959	Feb 1		14.6	6.6						
	Mar 1		19.9	8.2						
	Apr 1		28.0	11.4					34.1	
	May 1		30.6	7.9					34.0	
1960	Feb 1		13.4	4.4	4.8					
	Mar 1		19.0	7.1	7.9					
	Apr 1		23.0	7.9	8.7				29.2	
	May 1		27.2	6.4	7.1					27.5
1961	Feb 1		9.2	4.3	4.8					
	Mar 1		14.4	6.2	6.9					
	Apr 1		17.1	7.6	8.4				25.1	
	May 1		23.6	7.6	8.4					23.1
1962	Feb 1		18.8	7.9	8.7					
	Mar 1		21.8	9.4	10.4					
	Apr 1		25.4	11.4	12.5				35.3	
	May 1		25.0	4.8	7.2					30.4
	Jun 1		21.4							
1963	Feb 1		14.6	8.7	9.6					
	Mar 1		19.8	9.7	10.5					
	Apr 1	12.7	22.4	9.2	10.4				31.8	
	May 1	14.1	25.2	9.3	10.7					30.2
	Jun 1	2.7	19.5							

	Snow Survey Date	Arch Falls (7350 ft)	Devils Slide (8100 ft)	Hood Meadow (6600 ft)	Hood Meadow (new) (6600 ft)	Lick Creek (6860 ft)	Shower Falls (8100 ft)	May-June Streamflow Forecast (1000 AF)	April-July Streamflow Forecast	May-July Streamflow Forecast
1964	Jan 1					1.9				
	Feb 1	6.7	11.9	4.6	5.2	5.2				
	Mar 1	10.8	20.2	8.9	9.3	10.5				
	Apr 1	14.8	25.6	12.6	13.3	12.9			36.1	
	May 1	16.1	27.0	12.1	12.7	14.4				34.0
	May 15						13.6			
	Jun 1	10.8	25.9			0.0				
	Jun 15	1.2	20.4							
1965	Jan 1					4.9				
	Feb 1	11.0	21.8	8.4	9.6	9.5				
	Mar 1	14.8	26.3	11.6	12.7	12.5				
	Apr 1	16.0	29.8	13.5	14.9	15.1			40.0	
	May 1	16.8	32.0	10.0	12.3	10.4				37.0
	May 15	19.0	35.0	10.0	13.0	9.8	38.2			
	Jun 1	17.0	35.2	4.4	7.0	0.0	38.3			
	Jun 15	6.4	25.6				28.2			
	Jul 1		14.4				16.5			
1966	Jan 1		4.0			1.3	5.3			
	Feb 1	4.2	7.2	3.0	3.4	3.3	10.5			
	Mar 1	6.4	12.2	4.6	5.1	5.6	15.5			
	Apr 1	9.3	16.4	6.2	7.0	6.8	20.7		25.6	
	May 1	11.6	22.2	5.2	7.0	7.0	25.3			25.6
	May 15	7.2	19.5	0.0	0.0	0.0	21.5			
	Jun 1	1.4	14.5	0.0	0.0	0.0	16.3			
	Jun 15	0.0	4.0				2.8			
1967	Jan 1		6.6			3.9	8.3			
	Feb 1	8.8	15.2	7.4	8.2	8.1	18.3			
	Mar 1	12.2	21.4	9.8	11.0	11.5	24.3			
	Apr 1	16.8	26.8	13.4	15.0	13.6	31.8		44.0	
	May 1	18.7	30.2	13.4	14.6	13.5	33.2			42.2
	May 15	19.0	32.4	10.5	1.26	10.9	35.5			
	Jun 1	9.0	24.0		0.0	0.0	27.0			
	Jun 15	1.7	17.7				19.5			
	Jul 1		8.6				7.7			
1968	Jan 1		17.7	8.9	9.5	7.4	20.8			
	Feb 1	13.6	22.7	10.6	11.6	11.0	25.3			
	Mar 1	15.0	26.4	11.3	12.4	11.4	30.7			
	Apr 1	16.5	28.2	11.8	13.8	11.6	32.8		43.2	

	Snow Survey Date	Arch Falls (7350 ft)	Devils Slide (8100 ft)	Hood Meadow (6600 ft)	Hood Meadow (new) (6600 ft)	Lick Creek (6860 ft)	Shower Falls (8100 ft)	May-June Streamflow Forecast (1000 AF)	April-July Streamflow Forecast	May-July Streamflow Forecast
1968	May 1	20.3	35.2	12.3	15.2	14.2	38.5			42.2
	May 15	17.9	33.7	8.5	11.6	8.0	36.3			
	Jun 1	14.4	33.2	0.5	0.8	0.0	37.5			
	Jun 15	7.1	30.2				32.3			
	Jul 1		14.6				18.0			
1969	Jan 1		10.0	4.0	4.6	3.7	12.0			
	Feb 1	10.0	15.8	7.8	8.5	6.9	19.5			
	Mar 1	11.4	19.3	8.4	9.2	8.1	23.8			
	Apr 1	11.6	20.2	7.1	8.2	6.0	25.8		34.6	
	May 1	11.9	22.0	5.4	8.5	3.4	26.8			28.5
	May 15	8.6	20.4	0.5	0.6	0.0	21.3			
	Jun 1	0.3	11.6	0.0	0.0	0.0	11.5			
1970	Jan 1	7.6	13.0		8.2	6.2	14.7			
	Feb 1	11.6	19.6		11.9	9.6	23.2			
	Mar 1	13.4	24.3		10.0	10.2	28.3			
	Apr 1	19.2	32.6		16.2	15.5	36.7		50.0	
	May 1	23.3	40.5		19.6	19.7	44.9			51.6
	May 15	22.2	39.0		15.2	17.2	45.2			
	Jun 1	16.8	34.4		5.8	4.9	39.3			
1971	Jan 1	7.0	13.2		6.4	5.7	14.8			
	Feb 1	10.2	18.2		9.1	7.4	21.5			
	Mar 1	12.8	23.0		11.2	9.3	27.8			
	Apr 1	17.1	29.8		14.7	13.2	35.3		49.5	
	May 1	19.6	35.8		15.5	13.7	41.4			48.0
	May 15	15.4	32.6		7.4	1.9	35.8			
	Jun 1	14.4	31.6		0.7	0.0	37.5			
1972	Jan 1	5.8	9.8		4.6	3.9	12.2			
	Feb 1	9.0	14.7		7.9	6.8	18.0			
	Mar 1	10.4	18.4		9.2	8.6	22.5			
	Apr 1	12.9	23.6		11.0	8.0	28.0		37.0	
	May 1	14.2	26.1		10.7	5.6	30.7			34.0
	May 15	11.8	25.8		3.8	0.0	29.8			
	Jun 1	3.4	20.0		0.0	0.0	22.7			
1973	Jan 1	4.8	7.8		4.4	3.6	9.3			
	Feb 1	6.0	10.7		6.4	5.7	13.0			
	Mar 1									
	Apr 1	11.2	17.5		11.3	10.7	21.3		29.5	
	May 1									36.0
	May 15	16.8	26.6		13.6	13.2	28.5			
	Jun 1	11.0	20.7		0.0	0.0	23.7			

APPENDIX D

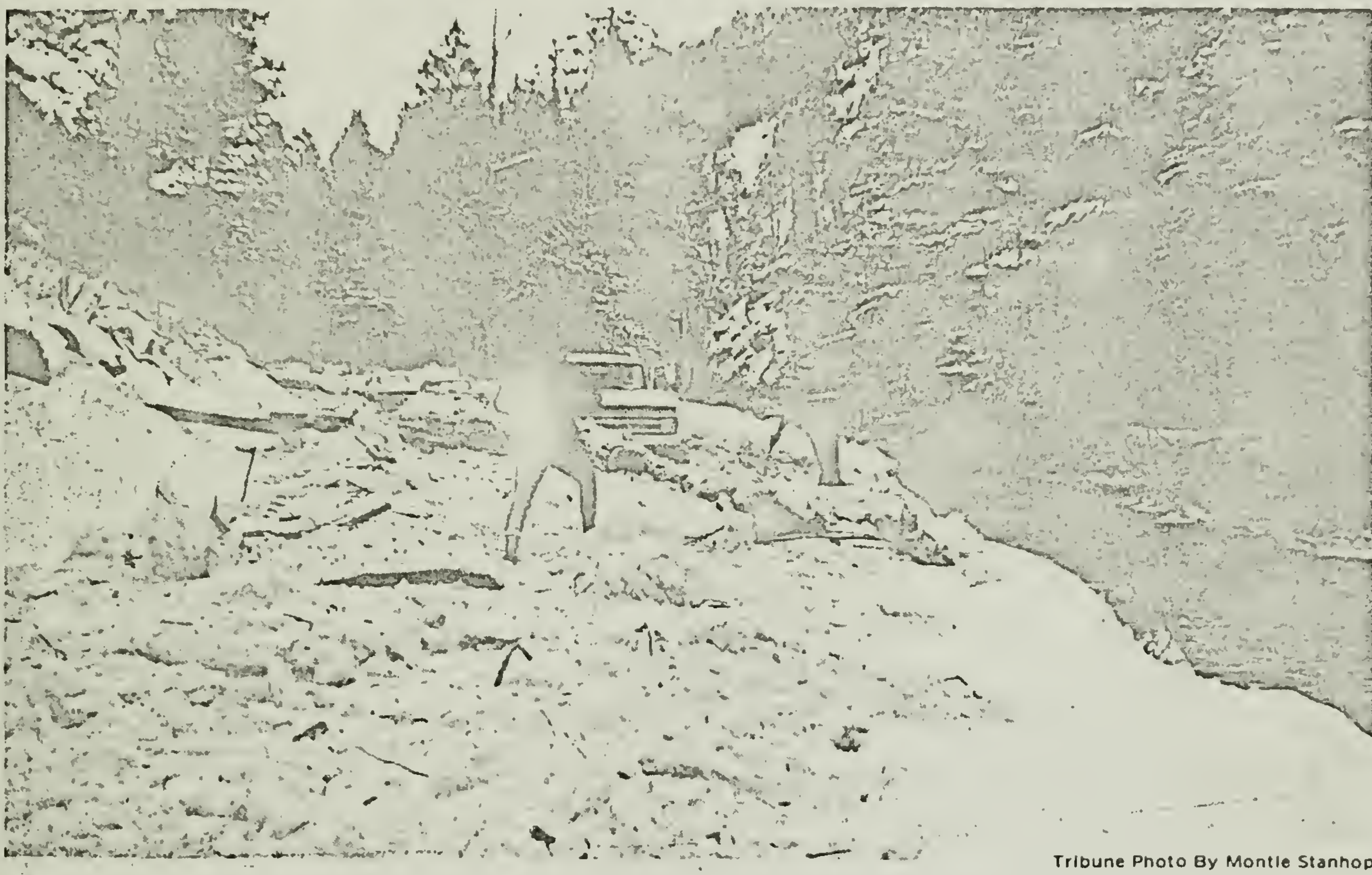
Newspaper Accounts of Hyalite Flooding

THE GALLATIN COUNTY T

And Belgrade Journal

Vol. No. XIX — 3 — Bozeman, Montana, Thursday, December 26, 1968

Outdoor Enthusiasts Stopped by Flood



Tribune Photo By Montie Stanhope

Hyalite Canyon Road presents a formidable picture as Montie Stanhope and David Thomas, of the Gallatin County Tribune, work their way out of the canyon Sunday afternoon.

It took them a little over three hours of shoveling ice, removing tree stumps and debris to get their vehicles down the road.

They were assisted by other persons (see photo) who wielded their axes in an effort to remove the trees.

Middle Creek can be seen to the right of the picture. The ice and water on the road was pushed by such pressure that it extended great distances at a number of points down the canyon on the road.

* * *

Anyone touring the Hyalite Canyon Sunday was in for a surprise when they returned home that afternoon.

The canyon road had become, of all things, flooded by Middle Creek.

Ice dams had been formed in the Creek by blocks of ice catching on logs and forming dams.

This caused the water to wash over the road, thereby picking up more ice and debris and causing flooding further down the creek.

After the water pushed the ice and debris ahead of it the road remained relatively clear.

Sheriff L.D.W. Anderson, who was called to the scene, called Forest Service personnel to the area.

"We wanted to make certain no one was trapped in the canyon," said Ross MacPherson, Bozeman district ranger, "There were 20 to 30 cars above the debris."

In one area of the Hyalite road water was backed up about a

(Continued on back Page)

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Officials Plan Schools

Christmas Shopping?

Nativity Scene Re-Created

Tribune Photo by Donna Brown

'e Security Bank and t Company of Boze- has depicted an ual nativity scene ozeman spectators. e theme of the Christmas scene is not unique, what does make it unusual is that the bank has used three live sheep and a burro.

It is this kind of a contribution to Christmas that brings smiles to the faces of passersby and highlights their day.

rymen:

(ntinued from front Page)

'lp accumulate data resent to Washing-

Losses have been listed as occuring from the following: loss due to selling hay at a discount; losses on cattle that they were forced to sell and then the extra cost of bringing out-of-state cattle to replenish their herds; trucking expenses on this item; losses incurred because they had to borrow money and pay interest on it while under restraint; losses incurred by boarding unproductive cows for a long period of time; losses incurred by having to pay for the testing of their hay.

Indemnities Paid

At the present time, only indemnities for milk produced and destroyed can be paid.

The ASCS office has received applications from three milk producers in three other counties, Fergus, Cascade and Lake, asking for indemnities.

These dairies were not restrained from selling milk but their processors refused to buy their milk because of pesticide content.

Indemnities totaling $43,716 were paid out to 26 dairymen earlier.

Officials Urge Public To Use Care

During the holiday season, Christmas thru New Years, Sheriff L.D. W. Anderson, Sgt. of the Highway Patrol, Buck Baldry and Chief of Police Ron Cutting, urge all the public to drive in a safe and prudent manner.

Above all, they urge, be careful of excessive use of intoxicating beverages throughout the holiday season.

All law enforcement agencies plan to be out in force to apprehend those who fail to obey the law. The cooperation of the public will be appreciated.

As a reminder to those who may receive firearms, the sheriff's office said it is unlawful to discharge firearms within three miles of the city limits.

The Sheriff's office also asks that those who have snowmobiles should remember they are not to travel any public streets, county roads or highways.

"Be courteous and obey the law. We wish a merry Christmas and a happy new year to everyone," says the Sheriff's office.

Officers Elected To Lodge No. 18

At the regular meeting of Bozeman Lodge No. 18, on Thursday, December 5, 1968, officers for the year 1969 were elected.

Elected were: Robert M. Holter, Worshipful Master; Raymond K. Shackleford, Senior Warden; James L. Simpson, Junior Warden; Kenneth E. Monroe, Secretary; William Holmes, Treasurer; Leslie E. House, Trustee.

Installation in conjunction with Gallatin Lodge #6 was held at 7:30 p.m., Thursday, December 19 at the Bozeman Lodge #18 Hall.

Preceeding the installation, a free pancake supper was served at 6:30 p.m. for all Masons.

Flood:

(continued from front page)

quarter of a mile.

This happened when a large tree fell into the creek and wedged behind a bridge causing the ice and water to back up.

"This is the first time Middle Creek has done this in four or five years," said MacPherson. "The last time it happened we had to use dynamite to break up a jam."

The road was closed the early part of the week to vehicles other than pickups or four-wheel drives.

The Three D Lumber company worked plowing the roads clear while the Forest Service cleared logs from under the bridges so this back-up wouldn't happen again.

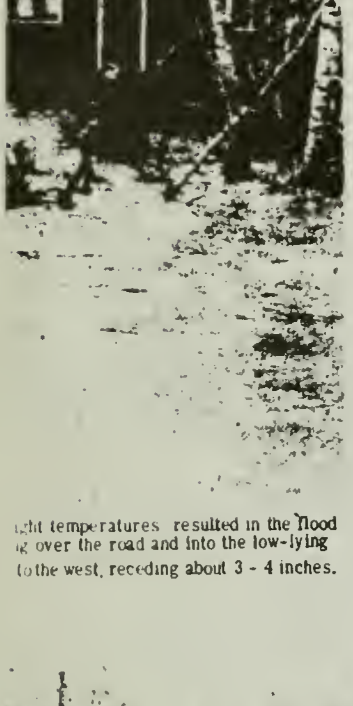
DAILY CHRONICLE

BOZEMAN, MONTANA, TUESDAY EVENING, MAY 19, 1970 — 10¢

Forecast

Bozeman-Considerable cloudiness through Wednesday with showers and thundershowers mostly during afternoons and evenings. Shower activity decreasing on Wednesday. Low tonight 39, high Wednesday 58.

ight temperatures resulted in the flood
g over the road and into the low-lying
to the west, receding about 3 - 4 inches.



Gallatin Valley Flooding Potential 'Critical' Now

By ANNABELLE PHILLIPS
Chronicle Staff Writer

The flooding potential in the Gallatin Valley is already critical and the weatherman holds the key to the future.

Currently, low elevation streams are raging out of their banks. And, at the present snowmelt rate, they will not reach their peak flow for about another two weeks.

The major streams — West Gallatin, Madison, Jefferson and Missouri — are high but, as yet, are causing no trouble. Peaking point for the waters of these rivers should be around mid - June.

The weather, however, can bring about a dramatic change.

A few days of high temperatures or rain, or a combination of the two, will bring about a rapid increase in all streamflows. Should this happen, most of the streams and rivers will be out of their banks.

The mountain snow pack this year is abnormally large, particularly at lower elevations. At many of the high elevation sites there was more than 100 inches of snow on May 15, Phil Farnes, snow survey supervisor for the Soil Conservation Service, said today.

Take the Hyalite Drainage, for instance. At Shower Falls, where the elevation is 8,100, there was 105 inches of snow and the water content was 45.2 inches. Snow depth at this point last year was 43 inches and water content 21.3 inches. The average water content for the period of 1953 to 1967 was 28.5 inches.

At Devils Slide, which also has an elevation if 8,100, the snow depth was 92 inches on May 15 and the water content 39 inches compared to a 21 inch snow depth and 8.6 inch water content a year ago.

At Lick Creek, 6,860 elevation, there was 50 inches of snow with a 17.2 water content. Last year on the same date there was no snow in this area.

There was 43 inches of snow at Hood Meadow, 6,600 elevation, and the water content was 17.2 Last year there was an inch of snow on May 15.

The Bridger Creek snow course paints about the same picture as far as the snow goes.

Bridger Bowl, with an elevation of 7,250, had 103 inches of snow and the water content was 43.4 inches. Last year there was 33 inches of snow with an 18.1 water content. The 1953 - 67 average water content was 27.6.

(See Flooding, Page 3)

Regents Stay Mum On MSU President

HELENA (AP) — One of three men has been chosen as president of Montana State University but the State Board of Regents is keeping the new president's name secret.

A source said the name would not be released until later this week after such details as when the new president can take over have been determined.

The board reached its decision during a meeting in Helena Monday. The Associated Press learned the new president of the 7,700-student school will be one of three men interviewed by the board this month.

They are:

— Carl W. McIntosh, president of California's Long Beach State College, which has more than 24,000 students and about 1,300 teachers. He was interviewed on May 1.

— Roy E. Huffman, Bozeman, MSU's vice president for research and director of its Endowment and Research Foundation. He was interviewed Sunday.

— Dean Stebbins, academic vice president of Michigan Technological University, Houghton, who was interviewed Monday.

Another candidate, who had been recommended by a special screening committee of the Board of Regents, withdrew his name from further consideration. He was Duane Ackre, dean of agriculture at South Dakota State University.

Since the death of MSU President Leon H. Johnson last June 18, Regents of the Montana University System have been looking for top candidates.

The school, second largest of the system's six units, has been operating under the direction of Acting President William A. Johnstone.

Johnstone, however, withdrew his name from consideration and is expected to return to his former position as administrative vice president when the new president takes over.

The announcement is expected within a day or two from the office of the system's executive secretary, Edward W. Nelson.

One source said the reason for the delay in announcing the name of the new president is to provide time to determine a number of details, such as the starting date.

Reds Step Up Attacks in South Vietnam

SAIGON (AP) — North Vietnamese and Viet Cong troops stepped up their attacks across South Vietnam sharply today in a new "highpoint" of activity apparently marking the 80th anniversary of the birth of Ho Chi Minh.

The Communist command's troops also threatened another Cambodian provincial capital in their efforts to keep open their supply lines through northern Cambodia and southern Laos.

The 37,000 American and [illegible]

World News Briefs

By THE ASSOCIATED PRESS

Eighteen days after President Nixon sent American combat troops into Cambodia, student protest strikes were under way at a reported 265 colleges. However, the disorders and scattered violence which characterized the first two weeks of protest have subsided.

WASHINGTON (AP) — All nine Negro members of the House, charging the White House with [illegible]

WASHINGTON (AP) — The old tactic of "jawboning" wages and prices into line, ridiculed and discredited by the Nixon administration, seems to be making a comeback.

Carefully choosing their words, Federal Reserve Chairman Arthur F. Burns and Housing Secretary George Romney both indicated Monday the government [illegible]

ed at MSU Poll

The spokesman did not say how many of the 200 Minuteman missiles in silos throughout central Montana will be replaced by the advanced model or when the conversions would take place.

He said minor changes in the silos will be needed for the conversions.

BUTTE (AP) — Members of the Butte police force voted 28-0 Monday to accept a national union as its bargaining agent, making Butte the first major city in Montana to embrace the idea of a unionized police department.

HELENA (AP)— Gov. Forrest H. Anderson Monday appointed Vince Caciari, Whitefish, to the Veterans Welfare Commission. Caciari replaces Kenneth Leslie, Great Falls, for a term ending May 18, 1975.

GREAT FALLS (AP) — Clyde Jarvis, president of the Montana Farmers Union, has been named by the Census Bureau to serve on the Census Advisory Committee on Agricultural Statistics.

HELENA (AP) — Daniel L. Herbert, Billings native, has been named Agricultural Statistician-in-Charge for the Montana Crop and Livestock Reporting Service in Helena.

Chicago Livestock

CHICAGO (AP) — (USDA) — Cattle 800; slaughter steers weak to 25 lower; few loads high choice and prime 1,225-1,275 lb slaughter steers 30.50-31.50; choice 1,000-1,250 lbs 29.75-30.50; good 27.75-29.00; choice 850-1,050 lb slaughter heifers 29.50-30.00; part load high choice and prime 1,075 lbs 30.50. good 27.00-28.50; utility and commercial cows 22.25-24.50. utility and commercial bulls 26.00-29.50.

Sheep 100; part deck good and choice 96 lb shorn slaughter lambs with No. 1 to 3 pelts with buck lambs included steady at 26.50.

THOMSON — Requiem Mass for Matilda [illegible] will be celebrated Wednesday [illegible] a.m. at the [illegible] [illegible]

[illegible]

... Ariz., Monday.

Mrs. Daems had been in Phoenix with her brother for a week.

Buckley, a native of Butte, was well known in the northwest and southwest for his position as district representative for Knights of Columbus. He had made his home in Phoenix for a number of years.

Survivors, in addition to his sister, include his widow, three daughters and numerous grandchildren.

Funeral Rites

WALTER OSWALD WEHRMAN

Funeral services for Walter Oswald Wehrman, of Belgrade, who died May 12, were conducted Monday afternoon at the Dahl and Vial Chapel.

The Rev. Robert Duryee of Belgrade officiated. Mrs. Al Potts was organist and Charles Rice, soloist.

Pallbearers were Lloyd H. Miller, Charles R. Wheeler, James Lee, Jess T. Erickson, Don Randell and Frank Reller.

Burial was in Sunset Hills Cemetery.

ALBERT SCHNEITER

Funeral services for Albert Schneiter of Belgrade, who died May 16, were held Monday afternoon at the Dahl and Vial Chapel.

The Rev. Lyle Onstad officiated. Mrs. R. D. Smiley was organist and Mrs. Fred Wehren was soloist.

Pall bearers were Clifford Barnes, Lane Barnes, Wallace Curtis, Ernest Wehren, Lloyd Hungate and Fred Wehren.

Burial was in Meadowview cemetery at Manhattan.

CARL E. VOGEL

Funeral services for Carl F (Charlie) Vogel of Route 1, who died May 14, were conducted Saturday afternoon at the Dokken-Nelson Sunset Chapel.

The Rev. Lyle Onstad officiated. Mrs. Willard Harper was organist and Charles Rice, soloist.

Pallbearers were Charles Williams, James D. Williams, ~~Frank DeHaan Rudy Vogel, Jim~~ Brender and David Vogel, Jr.

Burial was in Sunset Hills Cemetery.

EVELYN L. NELSON

Funeral services for Mrs. P. K. (Evelyn Lucia) Nelson were conducted Saturday morning at the Dokken — Nelson Sunset Chapel.

The Rev. Marcus Wist officiated. Mrs. Nita Botchek was organist.

Pallbearers were Alvin Goldenstein, Gerald Goldenstein, James Storey, Jim Breeden, William Rolfe and G. S. Burkhart.

Members of the Hereford Auxiliary and Home Demonstration Club attended in groups.

Burial was in Sunset Hills cemetery.

[illegible] RA HACKER

[illegible] services for Mrs. [illegible] Hacker of 531 North [illegible] died May 12, [illegible] Friday afternoon [illegible]

... on what is known as "the program concept of budgeting."

Program budgeting is essentially a system of planning and budgeting by programs which are oriented toward long-range goals.

To guide the 110 state agencies and institutions which are required to submit budgets to the Department of Administration, a 60-page manual of instructions has been prepared.

☆ Flooding

At Maynard Creek on Bridger, where the elevation is 6,210, there was 62 inches of snow and a 25.1 water content. Last year the snowdepth was 8 inches.

Sacajawea, with an elevation of 6,550, had a snow depth of 56 inches and water content measured 23.3 inches on May 15. Last year these measurements were nil.

The Upper Gallatin has its share of snow, too.

At Bear Basin, elevation 8,150, the snow depth on May 15 was 76 inches and the water content, 31.2.

There was 54 inches of snow at Little Park, elevation 7,400. The water content was 21 inches.

At Twenty - One Mile snow course in the Upper Gallatin the elevation is 7150 and the snow depth measured 42 inches. The water content measured 15.8.

The critical flood situation will continue to exist until the snow, particularly at the lower elevations, is gone.

The biggest problem right now is in the East Gallatin drainage area.

Bridger Creek is running rampant from the Story Mill Road westward.

Water is running around the doorsteps of homes in the area of the Story Mill Bridge. It's over the top of the Story Mill Road and Manley Lane and lying in pools in the low pasture spots in the area.

The dyke at the Riverside Country Club is holding back the high waters of the East Gallatin this year but to the west, this river is running out of its banks and causing headaches for people whose homes are in the low-lying areas, particularly in the vicinity of the Joe Nelson road.

An approach to the bridge on the Joe Nelson road washed out but was repaired by county crews Monday.

The waters are also reported high on Sixteen Mile Creek, which is running out of its banks on the middle fork.

Rocky Creek to the east of Bozeman is also high and out of its banks in the low spots.

Sourdough (Bozeman Creek) flowing through the eastern part of the city is posing no problems at present, although it's extremely high.

... basis for the final budget plan, known as the executive budget, which the governor recommends to the legislature.

Anderson said the improved program type of budget requested by the legislature in 19[illegible] marks a significant improvement in state budgeting.

The manual now being sent to state agencies explains that one reason for the emphasis on program budgeting stems from "concern that in the pursuit of short-run objectives we may be losing sight of larger goals."

Stock Market

NEW YORK (AP) — The stock market experienced a sharp, broad slump early this afternoon as the Dow Jones industrial average went below the 700 level.

At noon, the Dow average of 30 blue chips was off by 5.38 points at 697.43. Trading was quiet.

Today's downturn ended a rally that started late Thursday and sent the average ahead more than 17 points Friday.

Declining issues on the New York Stock Exchange held an almost 2-to-1 advantage over gainers. Winners and losers had been about even at the session's start.

The Associated Press 60-stock average was off 1.0 at 245.3. Industrials were off 2.6, rails off .5 and utilities, up .5.

Motors, rubber issues, aircrafts and electronics, were generally lower. Tobaccos and drugs were generally higher.

Analysts had expected the volume to increase today with the expiration Monday of the massive American Telephone & Telephone rights offering. The offering was believed to have drained off large quantities of funds from the stock market.

Prices on the Big Board's most-active list included Phelps Dodge, off 2 1/2 at 44; Memorex, off 3/8 at 77 5/8; Hewlett-Packard, off 1 [illegible] at 30[illegible]; Penn Central, off 1[illegible] at 14[illegible], and Air Products, off 1[illegible] at 37[illegible].

Prices on the American Stock Exchange's most-active list included Research-Cottrell, off 5[illegible] at 26[illegible]; Saxon Industries, off 3[illegible] at 46; Argus, up 1 at 4[illegible], and Deltona, off 4 at 27[illegible].

Portland grain

PORTLAND (AP) — May 18 close Portland Grain Exchange

Wheat bid to arrive market No. 1 bulk, 30-day shipment delivered coast White 5[illegible]

Hard Red Winter Ordinary 1.6[illegible]

Dark Northern Spring export 14 per cent 2.03

Dark Hard Winter Ordinary 1.6[illegible] 12 per cent 1.76 13 per cent 1.8[illegible]

Barley bid to arrive market 30-day shipment delivered coast No. 2, 45 lb western 4[illegible].00 No. 2 2-row or 3-row western 4[illegible].00

Coarse grain wholesale prompt delivery, bulk for f.o.b. trucks Portland Corn No. 2 yellow, eastern [illegible] Oats No. 2 38 lb western [illegible] Barley No. 2 45 lb western [illegible] Grain sorghum free market [illegible]

Car receipts — Wheat 5, barley 1, flour 34, corn 7, oats 1, millfeed 16.

... [illegible] with federal [illegible] meet the needs [illegible] and attention [illegible] will break [illegible] into [illegible] areas [illegible] administrative [illegible] management, [illegible] mental health.

Major program areas [illegible] ation agencies could [illegible] mary and secondary [illegible] higher education, special [illegible] tion and administration.

For agencies dealing with [illegible] resource development and [illegible] tion, the major program areas may be livestock and [illegible] fire, commercial and industrial, occupational and administration.

Within such major program areas, the agencies will list programs and subprograms.

The budget director [illegible] agencies has been asked [illegible] the instruction manual [illegible] before working on 1973-73 budget requests.

Frank Dunkle Hospitalized

HELENA (AP) — Mont. Fish and Game Department director Frank Dunkle has been hospitalized in Helena following a mild heart attack.

Keith A. Freseman, deputy Fish and Game director said the 45-year-old Dunkle was taken to St. Peters Hospital after he became ill at home.

A spokesman for the hospital said Dunkle was in "good condition and resting comfortably."

Dunkle has directed the department, one of the state's largest agencies, since his appointment in September of 19[illegible]

Field Work About 3 Weeks Behind

HELENA (AP) — Wet weather and muddy fields have hampered spring seeding. The Montana Weather, Crop and Livestock Bulletin said with field work about three weeks behind normal.

The Bulletin said in several areas of the state last week rain brought seeding to a standstill.

As of last Friday, seeding of spring wheat was 20 per cent complete, compared with [illegible] cent a year ago, the same d[illegible]

Barley drilling was [illegible] cent complete, the Bulletin compared with [illegible] per cent [illegible] year ago [illegible] reported [illegible] was listed as [illegible] per cent completed, [illegible] per cent less than [illegible] year ago [illegible]

The Bulletin said the [illegible] of winter wheat [illegible]

APPENDIX E

OPTIMAL SOLUTION

3) MATRIX	R.H.S.	ITER	STEPS	PIVS	OBJECTIVE	0	0 INFEAS	DETERMINANT	MIN. R/COST	NEW COL	OLD COL
M20	R7	2	1	5	-890.000000		.000	1.00000E 0	1.0000000	S2	R1

NAME	VALUE	ROW	RHS	PRICE IMPUTED VALUE (DUAL)	S3
Z* (Revenue)	890.000000	0	.000000	1.000000	1.000000
S2	60.000000	1	60.000000	10.000000	.000000
R2	80.000000	2	20.000000	10.000000	1.000000
R3	10.000000	3	10.000000	9.000000	-1.000000
R4	.000000	4	.000000	3.000000	.000000
W1	40.000000	5	100.000000	.000000	.000000
W2	100.000000	6	100.000000	.000000	1.000000
W3	100.000000	7	100.000000	.000000	.000000

SOLUTION BY ROW

-E.1-

NAME	VALUE	TRUE /COST/	REDUCED	ROW
R1	.000000	-2.000000	8.000000	
R2	80.000000	-10.000000	.000000	2
R3	10.000000	-9.000000	.000000	3
R4	.000000	-3.000000	.000000	4
S2	60.000000	.000000	.000000	1
S3	.000000	.000000	1.000000	
S4	.000000	.000000	6.000000	
W1	40.000000	.000000	.000000	5
W2	100.000000	.000000	.000000	6
W3	100.000000	.000000	.000000	7

SOLUTION BY COL. **OBJECTIVE FUNCTION**

FOR DISCUSSION OF RESULTS
PLEASE SEE THE TEXT.

LINEAR PROGRAMMING.

```
JN
•RESERVOIR OPERATION PROBLEM
BEGIN
FORMODE
ROW        0
R7
RHS
120
MATRIX

    PROBLEM HAS   8 ROWS,   10 COLUMNS, AND   20 MATRIX ENTRIES.
SOLVE
INSTALLED     3 SLACKS,     4 NON-SLACKS

REINVERTING AFTER     0TH ITERATION.    4 TRANSFORMATIONS WITH     8 ENTRIES, TIME=        .0000 TYPE 0
INVERSION COMPLETED    3 SLACKS,    0 POOR COLS,    4 TRANSFORMATIONS WITH    8 ENTRIES, TIME=        .0000

FEASIBLE ON ITERATION   0,     0 STEPS
```

APPENDIX F

DYNAMIC PROGRAMMING.

APP..E.

```
C  RESERVOIR  OPERATION  USING  DYNAMIC  PROGRAMMING
C  PROGRAMMED BY G.V.V.RAO, DEPT. OF CIVIL ENGINEERING, MONTANA STATE UNIVERSITY
C  LEGEND: D(I): DISCHARGE IN SEASON I.  I: SEASON.  J: ENDING STORAGE
C  K: BEGINNING STORAGE.  LF: LOSS DUE TO FLOOD.  LMEM: MIN. LOSS TO THAT POINT.
C  LMEMT: TEMPORARY VALUE FOR LMEM.  LR: RECREATION LOSS.  S: STORAGE.
C  X: INFLOW.
C  DISCLAIMER: NEITHER THE PROGRAMMER NOR M.S.U TAKE RESPONSIBILITY FOR THE
C  APPLICABILITY OF THIS PROGRAM TO OTHER SITUATIONS
       INTEGER S,X,D,SMEM                                                   DP010
       DIMENSION SMEM(5,0:2),LMEM(5,0:2),LR(0:2),L(0:2,0:2,5),LF(0:6)       DP020
       DIMENSION X(6),S(6),LMEMT(0:2),D(6),MST(5)                           DP030
C  READ  LOSS  FUNCTIONS  AND  INFLOW                                       DP040
       INPUT(105),(LR(J),J=0,2),(LF(I),I=0,6),(X(I),I=1,5),S(1)             DP050
C  STAGE  1.                                                                DP070
       I=1                                                                  DP075
       N=S(1)+X(1)                                                          DP080
       MST(1)=MINO(2,N)                                                     DP092
       NT=MST(1)                                                            DP096
       DO 100 J=0,NT                                                        DP100
       L(J,S(1),X(1))=LR(J)+LF(S(1)+X(1)-J)                                 DP110
       LMEM(1,J)=L(J,S(1),X(1))                                             DP120
       SMEM(1,J)=S(1)                                                       DP130
  100  CONTINUE                                                             DP150
C  STAGES  2TO5.                                                            DP160
       DO 200 I=2,5                                                         DP170
       N=MST(I-1)+X(I)                                                      DP180
       MST(I)=MINO(2,N)                                                     DP190
       NT=MST(I)                                                            DP194
       DO 150 J=0,NT                                                        DP200
       M1=J-X(I)                                                            DP210
       M=MAX(0,M1)                                                          DP220
       NN=MST(I-1)                                                          DP228
       DO 140 K=M,NN                                                        DP230
       L(J,K,X(I))=LR(J)+LF(K+X(I)-J)                                       DP240
       LMEMT(K)=L(J,K,X(I))+LMEM(I-1,K)                                     DP250
       IF(K.LE.0),GO TO130                                                  DP260
       IF(LMEMT(K).GT.LMEMT(K-1)),GO TO140                                  DP270
  130  LMEM(I,J)=LMEMT(K)                                                   DP280
       SMEM(I,J)=K                                                          DP290
  140  CONTINUE                                                             DP310
```

```
  15C CONTINUE                                                          DP320
  200 CONTINUE                                                          DP330
C  TRACING BACK                                                         DP340
      DO 300 J=0,2                                                      DP350
      IF(J.LE.0),GO TO250                                               DP360
      IF(LMEM(5,J).GT.LMEM(5,J-1)),GO TO300                             DP370
  250 MINL=LMEM(5,J)                                                    DP380
      S(6)=J                                                            DP390
  300 CONTINUE                                                          DP400
      DO 400 I=1,5                                                      DP420
      S(6-I)=SMEM(6-I,S(7-I))                                           DP430
      D(6-I)=S(6-I)-S(7-I)+X(6-I)                                       DP440
  400 CONTINUE                                                          DP450
      WRITE(108,5)                                                      DP452
    5 FORMAT(33X,'* DATA INPUT *')                                      DP454
      OUTPUT '          '                                               DP456
      WRITE(108,10)                                                     DP500
   10 FORMAT(10X,'STORAGE LEVEL',10X,'RECREATION LOSS'/)                DP510
      WRITE(108,20),(J,LR(J),J=0,2)                                     DP520
   20 FORMAT(15X,I1,22X,I1)                                             DP530
      WRITE(108,30)                                                     4P540
   30 FORMAT(///10X,'DRAFT',10X,'FLOOD LOSS'/)                          DP550
      WRITE(108,40),(I,LF(I),I=0,6)                                     DP560
   40 FORMAT(12X,I1,15X,I1)                                             DP570
      WRITE(108,50)                                                     DP580
   50 FORMAT(///10X,'SEASON',10X,'INFLOW'/)                             DP590
      WRITE(108,60),(I,X(I),I=1,5)                                      DP600
   60 FORMAT(13X,I1,14X,I1)                                             DP610
      WRITE(108,70),S(1)                                                DP620
   70 FORMAT(1H0,10X,'STARTING STATE=',I1)                              DP630
      WRITE(108,490)                                                    DP632
  490 FORMAT(1H1,31X,'* RESULTS OUTPUT *')                              DP634
      WRITE(108,500)                                                    DP640
  500 FORMAT(1H0,10X,'MATRIX OF OPTIMAL STORAGE AND CUMULATIVE LOSS')   DP650
      WRITE(108,510),(I,I=1,5)                                          DP660
  510 FORMAT(//10X,5(7X,I1,2X))                                         DP670
      DO 521 J=0,2                                                      DP680
      WRITE(108,520),J,(SMEM(I,J),LMEM(I,J),I=1,5)                      DP690
  520 FORMAT(1H0,8X,I1,5(5X,I1,2X,I2))                                  DP700
  521 CONTINUE                                                          DP710
      OUTPUT '          '                                               DP715
```

```
      0UTPUT '            0PTIMAL P0LICY'                              DP720
      X(6)=0                                                            DP722
      D(6)=0                                                            DP724
      WRITE(108,530)                                                    DP730
  530 F0RMAT(1H0,10X,'SEAS0N',10X,'ST0RAGE',10X,'INFL0W',10X,'0UTFL0W') DP740
      WRITE(108,540),(I,S(I),X(I),D(I),I=1,6)                           DP750
  540 F0RMAT(12X,I1,16X,I1,15X,I1,16X,I1)                               DP760
      WRITE(108,550) MINL                                               DP765
  550 F0RMAT(1H0,10X,'0PTIMAL L0SS=',I1)                                DP768
      END                                                               DP770
```

LØPE (GØ),(EXEC)

* DATA INPUT *

STØRAGE LEVEL	RECREATIØN LØSS
0	3
1	1
2	0

DRAFT	FLØØD LØSS
0	0
1	0
2	0
3	2
4	4
5	5
6	6

SEASØN	INFLØW
1	4
2	1
3	3
4	0
5	4

STARTING STATE=1

* RESULTS OUTPUT *

MATRIX OF OPTIMAL STORAGE AND CUMULATIVE LOSS

I = SEASON / J = STATE	1		2		3		4		5	
	SMEM	LMEM	SMEM	LMEM	SMEM	LMEM	SMEM	LMEM	SMEM	LMEM
0	1	8	2	7	2	10	2	6	2	12
1	1	5	2	3	1	6	2	4	2	9
2	1	2	2	2	1	3	2	3	1	6

——— OPTIMAL PATH.

OPTIMAL POLICY

SEASON	STORAGE	INFLOW	OUTFLOW
1	1	4	3
2	2	1	2
3	1	3	2
4	2	0	1
5	1	4	3
6	2	Ø	Ø

OPTIMAL LOSS=6

STOP 0